BATHYMETRICAL SURVEY
OF THE
FRESH WATER LOCHS
OF
SCOTLAND

UNDER THE DIRECTION OF
SIR JOHN MURRAY, K.C.B., F.R.S.
AND
LAURENCE PULLAR, F.R.S.E.

VOL. I.

To Dr. C. Dwight Marsh,
Bureau of Plant Industry,
U.S. Department of Agriculture.

Bathymetrical Survey of Scottish Fresh-Water Lochs

Report on the Scientific Results

Vol. I.

With the Compliments of
Sir John Murray and Mr Laurence Pullar

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BATHYMETRICAL SURVEY

OF THE

SCOTTISH FRESH-WATER LOCHS

Report on the Scientific Results

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OF THE

SCOTTISH FRESH-WATER LOCHS

CONDUCTED UNDER THE DIRECTION OF

SIR JOHN MURRAY
K.C.B., F.R.S., D.Sc., ETC.

AND

LAURENCE PULLAR
F.R.S.E., F.R.G.S.

DURING THE YEARS 1897 TO 1909

Report on the Scientific Results

VOLUME I

EDINBURGH
CHALLENGER OFFICE
1910

Dedicated

TO THE MEMORY OF

FREDERICK PATTISON PULLAR

WHO WAS DROWNED

WHILE ATTEMPTING TO SAVE THE LIVES OF OTHERS

ON 15TH FEBRUARY 1901

AT THE AGE OF TWENTY-FIVE YEARS

*He took an active part in the initiation
of this systematic survey of the
Scottish Fresh-water Lochs*

PREFACE

This publication consists of six volumes, two of text and four of maps, and gives an account of the work done, of the observations recorded, and of most of the results obtained, during an investigation into the bathymetry of the fresh-water lochs or lakes of Scotland between the years 1897 and 1909.

Although the determination of the depths of the lakes, and of the general form of the basins in which they lie, made up the principal work of the Survey, still a very large number of observations were carried out in other branches of the science of limnography. Many of these observations and the results were published from time to time, as the work proceeded, in scientific journals, while others now appear in print for the first time.

Volume I. consists for the most part of new matter. It includes numerous articles dealing with the general results of the researches from the topographical, geological, physical, chemical, and biological points of view, a comparison of Scottish lakes with lakes in other parts of the world, and various theoretical considerations. These articles have been written chiefly by gentlemen who have taken an active part in the field-work of the Survey. This volume also contains an extensive bibliography of books and special papers referring to lakes.

Volume II. contains the special descriptions of the lakes, the maps of which appear in Volumes III., IV., V., and VI. Throughout the text will be found numerous index-maps, showing the drainage areas of the districts in which the lochs are situated, together with other illustrations.

The bathymetrical maps have all appeared during the past eight years in the Journal of the Royal Geographical Society or in an extra publication of the same Society; and some of the maps have also been published in the

Magazine of the Royal Scottish Geographical Society. These maps consist of two series. In the first series (Volumes III. and IV.), the contours of depth in the lakes are shown in shades of blue, and the contours of the height of the surrounding land are shown in brown shades of colour; in the second series (Volumes V. and VI.), the contours of depth are shown in shades of blue, the brown shades on the land being omitted.

In addition to the bathymetrical maps, there are also a few maps showing the surface geology, the rainfall, and other physical features of some of the districts.

These maps have all been prepared and printed by Dr J. G. Bartholomew, and we desire to express our indebtedness to him for the care with which these have been produced, and for his assistance and advice in many directions. We are also indebted to Messrs G. Cornwall & Sons, Aberdeen, for their assistance and advice with regard to the binding of the maps, and to Messrs Neill & Co., Edinburgh, for their advice in connection with the letterpress.

We feel confident that the whole investigation has resulted in very substantial contributions to knowledge. Some of the observations—those regarding the temperature seiche, and the variation of the viscosity of the water with temperature, for example—throw much light on obscure oceanographical problems. Most of the observations could, with advantage, have been carried further, by means of improved instruments and methods suggested during the progress of the work, but it was found necessary to terminate the survey, at least in the meantime, and to review what had been accomplished. We are conscious of many shortcomings.

In conclusion, we tender our best thanks to all who have assisted us in carrying these investigations to a successful conclusion.

JOHN MURRAY.
LAURENCE PULLAR.

Challenger Office, Edinburgh,
February 1910.

CONTENTS

VOLUME I

VOLUME II

PART I

PART II

Descriptions of Scottish Fresh-water Lochs, the maps of which, showing only the lake-contours in shades of blue, are bound in Volumes V. and VI. :—

VOLUME III

VOLUME IV

VOLUME V

VOLUME VI

In addition to the maps showing the depths of the lochs, the following maps are included in Vol. III. :—

Plate	I.	Head-waters of the Forth—Orography and drainage areas.
Plate	II.	„ „ „ —Surface geology.
Plate	III.	„ „ „ —Mean annual rainfall.
Plate	XIV.	Temperature Section of Loch Ericht.
Plate	XXXIV.	Head-waters of the Tay—Surface geology.
Plate	XLII.	Assynt District—Surface geology.
Plate	LI.	Loch Maree District—Surface geology.

STATISTICAL TABLES OF THE SCOTTISH FRESH-WATER LOCHS

(*Surveyed during the years* 1897 *to* 1909)

During the course of the Lake Survey work 562 of the Scottish fresh-water lochs were surveyed. These include all the principal lochs of the country, and a very large number of the smaller and less important ones. As a matter of fact, all lochs were surveyed on which boats could be found at the time the work was being carried out. To have included all the smaller highland and less accessible lochs and tarns would have very greatly increased the expense and the time involved. To transport a boat to many of the remote lochs in the Highlands would have entailed much labour and difficulty, not to speak of the objections of proprietors, keepers, and others, who do not wish to have grouse moors and deer forests disturbed at a time of the year when the lochs are most accessible.

The general results of the survey work are, however, in no way affected by these smaller lochs having been excluded, for a great many lochs have been surveyed in all districts of the country.

The following tables are intended to summarise the results which are given in detail in Volume II. of this Report.

Table I. shows the lakes arranged according to their lengths.

Table II. shows the lakes arranged according to their superficial areas.

Table III. shows the lakes arranged according to their maximum depths.

Table IV. shows the lakes arranged according to their mean depths.

Table V. shows the lakes arranged according to the volume of water in each.

Table VI. shows:—

(*a*) The number of lakes surveyed in the various river basins;

(*b*) The number of soundings taken in the lakes of the various river basins;

(*c*) The volume of water in the lakes of the various river basins in millions of cubic feet;

(*d*) The superficial area of the lakes in the various river basins;

(*e*) The extent of the drainage area in the various river basins, together with the ratio of the drainage area to the superficial area of the lakes.

The information in Table VI. is extracted from the tables given in greater detail in the descriptions which will be found in Volume II. of this Report.

From this table it will be seen that 562 lochs have been surveyed, and that the number of soundings recorded on the maps of these lochs is 59,195. The actual number taken exceeds 60,000. The aggregate area of the water-surface is over 340 square miles, and therefore the average number of soundings per square mile of surface is 174.

The aggregate volume of water contained in these 562 lochs is estimated at about 1,015,814 millions of cubic feet, or nearly 7 cubic miles. The area drained by the lochs is about 6669 square miles, or about 19½ times the area of the lochs.

TABLE I

Fresh-water Lochs of Scotland (sounded by the Lake Survey) arranged according to Length

Loch.	Length. Miles.	Loch.	Length. Miles.
1. Awe (Etive)	25·47	55. Beoraid	3·43
2. Ness	24·23	56. Dùn na Seilcheig	3·41
3. Lomond	22·64	57. Eilt	3·37
4. Shiel	17·40	58. na Meide	3·33
5. Shin	17·22	59. Avich	3·30
6. Tay	14·55	60. Stack	3·27
7. Ericht	14·50	61. Affric	3·20
8. Maree	13·46	62. Ossian	3·20
9. Arkaig	12·00	63. Skinaskink	3·16
10. Morar	11·68	64. Cliff	3·16
11. Lochy	9·78	65. Coir' an Fheàrna	3·15
12. Rannoch	9·70	66. Bà (Mull)	3·04
13. Katrine	8·00	67. Obisary	3·03
14. Langavat (Lewis)	7·86	68. Merkland	3·02
15. Laggan	7·04	69. St Mary's	3·02
16. Quoich	6·95	70. nan Cuinne	3·00
17. Fannich	6·92	71. Watten	3·00
18. Earn	6·46	72. Trealaval	2·90
19. Assynt	6·36	73. Càm	2·76
20. Naver	6·18	74. Loyne (East)	2·75
21. Hope	6·13	75. Tummel	2·75
22. Eck	6·02	76. Suainaval	2·68
23. Fionn (Gruinard)	5·76	77. a' Bhraoin	2·66
24. Doon	5·64	78. Beinn a' Mheadhoin	2·64
25. Laidon	5·30	79. nan Eun (N. Uist)	2·63
26. Treig	5·10	80. Fadagoa	2·60
27. Luichart	5·05	81. Garry (Tay)	2·55
28. Garry (Ness)	4·90	82. Strom	2·54
29. Mhor	4·84	83. Tulla	2·50
30. Harray	4·84	84. Talla	2·47
31. Ken	4·62	85. Fionn (Kirkaig)	2·40
32. Frisa	4·50	86. nan Geireann (Mill)	2·39
33. Scadavay (East)	4·50	87. Calder	2·32
34. Laoghal	4·46	88. Morie	2·30
35. Clunie (Ness)	4·28	89. Ard	2·30
36. Mullardoch	4·16	90. Grunavat	2·26
37. More (Laxford)	4·11	91. Ruthven	2·26
38. Monar	4·10	92. Muick	2·22
39. Veyatie	4·05	93. Langavat (Benbecula)	2·20
40. Glass	4·03	94. Lochindorb	2·18
41. Expansions of River Dee	4·02	95. Bà (Tay)	2·15
42. Oich	4·02	96. Bad a' Ghaill	2·13
43. Vennachar	4·00	97. Boardhouse	2·03
44. Lubnaig	4·00	98. Grennoch	2·02
45. Damh (Torridon)	3·93	99. Dhùghaill (Carron)	2·02
46. Lurgain	3·87	100. Skebacleit	2·00
47. Scadavay (West)	3·80	101. Swannay	2·00
48. Stenness	3·79	102. Eilde Mòr	1·98
49. na Sheallag	3·74	103. Migdale	1·92
50. Fada (Ewe)	3·74	104. na Sàlach Uidhre	1·90
51. Leven	3·65	105. Urigill	1·86
52. Brora	3·53	106. Beannachan	1·85
53. Voil	3·50	107. Arienas	1·85
54. a' Chroisg	3·47	108. Achall	1·83

Table I—*continued*

Loch.	Length. Miles.	Loch.	Length. Miles.
109. na h-Earba (West)	1·80	169. Shurrery	1·28
110. Fada (N. Uist)	1·80	170. Harperrig	1·27
111. Woodhall	1·79	171. Buidhe (Fleet)	1·27
112. a' Bhealaich (Gairloch)	1·78	172. na h-Earba (East)	1·27
113. Thom	1·78	173. Hunder	1·26
114. Lyon	1·74	174. Kirbister	1·26
115. Freuchie	1·74	175. Bunacharan	1·26
116. na h-Oidhche	1·73	176. an t-Seilich	1·26
117. Castle Semple	1·72	177. Martnaham	1·26
118. Eye	1·72	178. Achray	1·25
119. an Daimh (Shin)	1·71	179. Rescobie	1·24
120. Baddanloch	1·70	180. Beannach (Inver)	1·24
121. Chon (Forth)	1·70	181. Urrahag	1·24
122. Nell	1·68	182. Loch	1·23
123. Trool	1·68	183. Droma	1·23
124. Heouravay	1·68	184. Dubh (Gruinard)	1·23
125. Leum a' Chlamhain	1·62	185. Muckle Water	1·21
126. Fiodhaig	1·61	186. an Gead	1·21
127. Heilen	1·60	187. Sloy	1·21
128. Olavat	1·60	188. Lowes (Tay)	1·20
129. Fad	1·60	189. Castle (Bladenoch)	1·20
130. Menteith	1·60	190. Inbhir	1·20
131. Ashie	1·60	191. Maberry	1·19
132. a' Bhealaich (Naver)	1·60	192. Dee	1·18
133. a' Bhaid-Luachraich	1·57	193. a' Bharpa	1·18
134. Creagach	1·57	194. Garbhaig	1·18
135. Owskeich	1·56	195. an Duin (Spey)	1·18
136. Gladhouse	1·56	196. Tralaig	1·16
137. an Dithreibh	1·55	197. an Stromore	1·15
138. Scamadale	1·54	198. na Leitreach	1·14
139. an Ruathair	1·54	199. Oban nam Fiadh	1·13
140. Garve	1·54	200. Sgamhain	1·12
141. a' Chlàir (Helmsdale)	1·53	201. Calavie	1·12
142. Fada (Gruinard)	1·52	202. Killin	1·12
143. Mochrum	1·50	203. nam Breac	1·12
144. a' Ghriama	1·50	204. an Eilein (Spey)	1·10
145. Threipmuir	1·50	205. Milton	1·10
146. Girlsta	1·48	206. Meiklie	1·10
147. Finlas	1·46	207. Auchenreoch	1·08
148. Poulary	1·46	208. Forfar	1·07
149. an Tomain	1·45	209. Crogavat	1·06
150. Caravat	1·45	210. Kinord	1·06
151. Lungard	1·44	211. Benachally	1.05
152. Dilate	1·43	212. a' Bhaillidh	1·04
153. an Dùin (N. Uist)	1·40	213. Turret	1·04
154. Cròcach	1·40	214. More Barvas	1·04
155. Gorm Loch Mòr	1·39	215. Gartmorn	1·04
156. Clair (Ewe)	1·38	216. Insh	1·03
157. Lintrathen	1·38	217. Moy	1·03
158. Black (Ryan)	1·36	218. Borralan	1·03
159. Strandavat	1·36	219. Pattack	1·03
160. a' Chuilinn (Conon)	1·35	220. Morlich	1·02
161. Iubhair	1·35	221. Tingwall	1·02
162. Kernsary	1·35	222. an Staca	1·02
163. Coulin (Ewe)	1·33	223. ic Colla	1·00
164. Kilbirnie	1·32	224. na Craobhaig	1·00
165. Spiggie	1·30	225. Vatandip	1·00
166. Hundland	1·30	226. Gainmheich (South)	1·00
167. Knockie	1·30	227. Wester	1·00
168. Loyne (West)	1·28	228. Drunkie	1·00

TABLE I—*continued*

Loch.	Length. Miles.	Loch.	Length. Miles.
229. Arklet	1·00	289. na Creige Duibhe	0·80
230. Doine	1·00	290. na Moracha	0·80
231. an Lagain	1·00	291. Kindar	0·80
232. Skaill	0·98	292. Builg	0·80
233. Skene (Dee)	0·98	293. Kirk Dam	0·80
234. na Beinne Bàine	0·97	294. Crò Criosdaig	0·80
235. Bodavat	0·96	295. Eela	0·79
236. Cùil na Sìthe	0·96	296. Chaluim	0·78
237. Daimh (Tay)	0·96	297. Skiach	0·78
238. Ailsh	0·95	298. Hempriggs	0·77
239. Cuil Airidh a' Flod	0·94	299. Lochrutton	0·77
240. Alvie	0·94	300. Airidh na Lic	0·76
241. Gryfe	0·94	301. Raoinavat	0·76
242. na Cuaich	0·94	302. Gelly	0·76
243. Con (Tay)	0·94	303. Lundie (Garry)	0·76
244. Dungeon	0·93	304. na Mòine Buige	0·76
245. Skealtar	0·93	305. Araich-Lin	0·75
246. Clousta	0·92	306. an Laig Aird	0·74
247. Dubh (Gairloch)	0·92	307. Davan	0·74
248. Nant	0·90	308. nam Breac Dearga	0·74
249. Tollie	0·90	309. Muckle Lunga	0·74
250. Hermidale	0·90	310. nan Deaspoirt	0·74
251. Huna	0·90	311. Bran	0·74
252. Bradan	0 90	312. Howie	0·74
253. Fitty	0·90	313. a' Ghobhainn	0·73
254. Peppermill	0·90	314. Druim Suardalain	0·73
255. North-house	0·90	315. na Lairige	0·73
256. Ochiltree	0·89	316. Stacsavat	0·72
257. White (Ryan)	0·88	317. an Drainc	0·72
258. Ceò-Glas	0·88	318. Skeen (Annan)	0·72
259. Allt an Fheàrna	0·88	319. Sguod	0·72
260. Eigheach	0·88	320. Broom	0·72
261. Achilty	0·87	321. Skerrow	0·70
262. Tankerness	0·86	322. na Bì	0·70
263. More (Thurso)	0·86	323. Eileach Mhic' ille Riabhaich	0·70
264. a' Bhaid Daraich	0·86	324. Teàrnait	0·70
265. Crombie Den	0·86	325. Syre	0·70
266. Lùnn dà-Bhrà	0·86	326. Caol na Doire	0·70
267. Drumellie	0·86	327. Long	0·70
268. a' Mhuillin	0·84	328. nan Lann	0·70
269. Vaara	0·84	329. Carlingwark	0·70
270. Achanalt	0·84	330. Benisval	0·70
271. Callater	0·84	331. Bad an Sgalaig	0·69
272. Lowes (Tweed)	0·84	332. Spynie	0·69
273. Oban a' Chlachain	0·84	333. Tarff	0·69
274. Ussie	0·84	334. Tormasad	0·69
275. Lindores	0·84	335. Seil	0·68
276. Scarmclate	0·84	336. Ghuiragarstidh	0·68
277. Truid air Sgithiche	0·84	337. Baile a' Ghobhainn	0·68
278. a' Bhuird	0·84	338. Crunachan	0·68
279. na Moine	0·83	339. Rosebery	0·68
280. Castle (Annan)	0·83	340. Drummond	0·68
281. Braigh Horrisdale	0·82	341. Kennard	0·68
282. Ghuilbinn	0·82	342. Deoravat	0·68
283. na h-Achlaise	0·82	343. Clings	0·68
284. St John's	0·82	344. na h-Airidh Sléibhe	0·68
285. Awe (Inver)	0·82	345. Dornal	0·68
286. Giorra	0·82	346. Bogton	0·66
287. an Tuirc	0·81	347. Portmore	0·66
288. Linlithgow	0·80	348. an Eilein (Gairloch)	0·66

TABLE I—*continued*

Loch.	Length. Miles.	Loch.	Length. Miles.
349. a' Bhealaich (Alsh)	0·66	409. Whinyeon	0·56
350. Stormont	0·66	410. a' Chonnachair	0·56
351. Morsgail	0·66	411. an Nostarie	0·56
352. Dibadale	0·66	412. Whitefield	0·56
353. an t-Slagain	0·65	413. na Ceithir Eileana	0·56
354. Ordie	0·64	414. Sròn Smeur	0·56
355. Gleann a' Bhearraidh	0·64	415. Gown (South)	0·55
356. Grass	0·64	416. Moraig	0·55
357. Raonasgail	0·64	417. Monzievaird	0·55
358. Sealbhag	0·64	418. Coire nam Meann	0·54
359. Bosquoy	0·64	419. Kilconquhar	0·54
360. Valtos	0·64	420. na Stainge	0·54
361. Beannach (Gruinard)	0·63	421. a' Mhiotailt	0·54
362. Arthur	0·63	422. Bruadale	0·54
363. Edgelaw	0·62	423. Asta	0·53
364. Bad a' Chrotha	0·62	424. Uanagan	0·52
365. Roer	0·62	425. Burga	0·52
366. Craggie	0·62	426. Allan	0·52
367. na Déighe fo Dheas	0·62	427. an Losgainn Mòr	0·52
368. Allt na h-Airbhe	0·62	428. Kemp	0·52
369. Doire nam Mart	0·62	429. Monk Myre	0·52
370. an Laghair	0·62	430. nan Druimnean	0·52
371. Dochart	0·62	431. Lochinvar	0·52
372. Fiart	0·62	432. Flugarth	0·52
373. an Tachdaidh	0·62	433. a' Bhaille	0·52
374. Clunie (Tay)	0·62	434. na Coinnich	0·51
375. Urr	0·62	435. an Leòid	0·50
376. Dochard	0·62	436. an t-Seasgain	0·50
377. Scaslavat	0·62	437. Aithness	0·50
378. a' Chlachain (Lewis)	0·62	438. Balgavies	0·50
379. Black (Etive) (East)	0·62	439. Burntisland	0·50
380. nam Faoileag	0·62	440. Harperleas	0·50
381. Leitir Easaich	0·61	441. Eldrig	0·50
382. a' Choire	0·61	442. Littlester	0·50
383. Harelaw	0·60	443. Kilcheran	0·50
384. an Droighinn	0·60	444. na Doire Daraich	0·50
385. Leodsay	0·60	445. Tarruinn an Eithir	0·50
386. Isbister	0·60	446. na Sreinge	0·50
387. Burraland	0·60	447. Mhic' ille Riabhaich	0·49
388. Sabiston	0·60	448. Hosta	0·49
389. Snarravoe	0·60	449. Breaclaich	0·49
390. Ederline	0·60	450. Peerie	0·48
391. Airidh na Ceardaich	0·60	451. a' Chlachain (Nairn)	0·48
392. Dhomhnuill Bhig	0·60	452. nan Eun (Ness)	0·48
393. an Iasgaich	0·59	453. Monikie (South)	0·48
394. Lochaber	0·59	454. Punds	0·48
395. Derculich	0·59	455. na Craige	0·48
396. Bhradain	0·58	456. a' Ghlinne Dorcha	0·47
397. nan Gabhar	0·58	457. Moor Dam	0·47
398. Phitiùlais	0·58	458. Lundie (Clunie)	0·46
399. Craiglush	0·58	459. Shechernich	0·46
400. Butterstone	0·58	460. Liath	0·46
401. Veiragvat	0·58	461. Essan	0·46
402. Derclach	0·58	462. Fithie	0·46
403. Soulseat	0·58	463. a' Phearsain	0·46
404. Gown (North)	0·57	464. nan Eun (Tay)	0·45
405. Black (Etive) (West)	0·56	465. a' Vullan	0·45
406. Black (Etive) (Mid)	0·56	466. Rae	0·44
407. White of Myrton	0·56	467. Holl	0·44
408. Dhùgaill (Torridon)	0·56	468. an Dùna	0·44

TABLE I—*continued*

Loch.	Length. Miles.	Loch.	Length. Miles.
469. Brow	0·44	517. Brough	0·32
470. Lochnaw	0·44	518. Geal	0·32
471. Dallas	0·43	519. Kilchoan (Upper)	0·32
472. Mill	0·43	520. a' Chaoruinn	0·32
473. Dubh (Ailort)	0·43	521. Sior	0·32
474. Muck	0·42	522. na Garbh-Abhuinn Ard	0·32
475. Clickhimin	0·42	523. Kinghorn	0·31
476. Harrow	0·42	524. a' Chladhaich	0·31
477. Kirk	0·42	525. nan Losganan	0·30
478. Monikie (North)	0·42	526. Hightae Mill	0·30
479. Gamhna	0·42	527. Dubh-Mòr	0·30
480. Lochenbreck	0·42	528. Beag	0·30
481. na h-Ealaidh	0·42	529. Sand	0·29
482. na Claise Feàrna	0·42	530. Duartmore	0·29
483. nan Geireann	0·41	531. Clubbi Shuns	0·29
484. Lure	0·40	532. Hostigates	0·28
485. Sandy	0·40	533. Scoly	0·28
486. nan Garbh Chlachain	0·40	534. nan Ràth	0·28
487. Bhac	0·38	535. Black (Tay)	0·28
488. Brouster	0·38	536. Drumlamford	0·28
489. Fleet	0·38	537. nan Aùscot	0·27
490. Hoglinns	0·38	538. na Creige Léithe	0·27
491. Collaster	0·38	539. Cults	0·26
492. na Beiste	0·37	540. Skae	0·26
493. Màma	0·37	541. Cornish	0·26
494. Fyntalloch	0·37	542. Kirriereoch	0·26
495. Auchenchapel	0·37	543. Eion Mhic Alastair	0·25
496. Birka	0·36	544. na Beithe	0·25
497. Aboyne	0·36	545. an Dubh (Lochy)	0·24
498. na Garbh-Abhuinn	0·36	546. an Tairbeirt Stuadhaich	0·23
499. Hoil	0·36	547. Magillie	0·22
500. Blairs	0·36	548. Tùtach	0·22
501. Gainmheich (North)	0·36	549. Crann	0·22
502. a' Bhainne	0·36	550. Setter	0·22
503. Kilchoan (Lower)	0·36	551. Pitlyal	0·21
504. Tilt	0·35	552. na Gealaich	0·21
505. Anna	0·35	553. Choire na Cloich	0·20
506. Aslaich	0·35	554. Dubh (Forth)	0·20
507. Fingask	0·35	555. Loch on Eilean Subhainn (Maree)	0·18
508. Dubh (Etive)	0·35	556. Dubh (Ness)	0·18
509. Maol a' Choire	0·34	557. na h-Eaglais	0·16
510. Laide	0·34	558. Uaine	0·14
511. White (Tay)	0·34	559. St Margaret's	0·13
512. Duddingston	0·34	560. Dhu (Portsonachan)	0·12
513. Kinellan	0·33	561. Allt na Mult	0·12
514. Fender	0·33	562. Rainbow	0·10
515. Ree	0·32		
516. Buidhe (Tay)	0·32		

TABLE II

Fresh-water Lochs of Scotland (sounded by the Lake Survey) arranged according to Superficial Area

Loch.	Area. Square Miles.	Loch.	Area. Square Miles.
1. Lomond	27·45	54. nan Cuinne	1·15
2. Ness	21·78	55. Coir' an Fheàrna	1·15
3. Awe (Etive)	14·85	56. Tulla	1·10
4. Maree	11·03	57. Clunie (Ness)	1·10
5. Morar	10·30	58. Ossian	1·03
6. Tay	10·19	59. Bad a' Ghaill	1·02
7. Shin	8·70	60. Menteith	1·02
8. Shiel	7·56	61. Càm	1·01
9. Rannoch	7·37	62. a' Chroisg	1·00
10. Ericht	7·21	63. Stack	0·99
11. Arkaig	6·24	64. St Mary's	0·99
12. Lochy	5·91	65. Baddanloch	0·99
13. Leven	5·30	66. Tummel	0·98
14. Katrine	4·78	67. Lubnaig	0·96
15. Earn	3·91	68. Ard	0·94
16. Harray	3·78	69. Swannay	0·94
17. Fannich	3·60	70. Suainaval	0·94
18. Fionn (Gruinard)	3·52	71. Veyatie	0·93
19. Langavat (Lewis)	3·45	72. Morie	0·92
20. Assynt	3·10	73. Bà (Tay)	0·92
21. Laggan	2·97	74. Boardhouse	0·89
22. Quoich	2·86	75. Brora	0·88
23. Laoghal	2·55	76. Voil	0·88
24. Stenness	2·46	77. na Meide	0·87
25. Treig	2·41	78. Muick	0·85
26. Hope	2·35	79. Lochindorb	0·84
27. Naver	2·26	80. an Ruathair	0·82
28. Skinaskink	2·09	81. Affric	0·82
29. Doon	2·04	82. Beinn a' Mheadhoin	0·79
30. Dùn na Seilcheig	1·95	83. Urigill	0·78
31. Glass	1·86	84. Oich	0·76
32. Laidon	1·80	85. an Dithreibh	0·74
33. Luichart	1·76	86. Fada (N. Uist)	0·70
34. Garry (Ness)	1·75	87. Merkland	0·69
35. Eck	1·70	88. nan Geireann (Mill)	0·68
36. Frisa	1·69	89. Expansions of River Dee	0·67
37. Mhor	1·69	90. a' Bhraoin	0·66
38. Vennachar	1·61	91. Arienas	0·66
39. More (Laxford)	1·46	92. Eilt	0·66
40. Watten	1·45	93. Owskeich	0·65
41. Fada (Ewe)	1·44	94. Lintrathen	0·62
42. na Sheallag	1·37	95. Garry (Tay)	0·61
43. Ken	1·36	96. Trealaval	0·61
44. Damh (Torridon)	1·33	97. Grunavat	0·60
45. Calder	1·32	98. Gladhouse	0·59
46. Lurgain	1·26	99. Garve	0·59
47. Bà (Mull)	1·21	100. Fiodhaig	0·58
48. Avich	1·21	101. Caravat	0·58
49. Scadavay (West)	1·20	102. Ruthven	0·57
50. Mullardoch	1·18	103. Beoraid	0·55
51. Monar	1·17	104. Leum a' Chlamhain	0·55
52. Obisary	1·17	105. na h-Oidhche	0·54
53. a' Chlàir (Helmsdale)	1·17	106. Freuchie	0·54

TABLE II—*continued*

Loch.	Area. Square Miles.	Loch.	Area. Square Miles.
107. Achall	0·52	166. Heilen	0·30
108. nan Eun (N. Uist)	0·52	167. Skebacleit	0·30
109. Ashie	0·52	168. na h-Achlaise	0·29
110. Thom	0·52	169. Kinord	0·29
111. Strom	0·52	170. a' Bhaillidh	0·29
112. a' Bhaid-Luachraich	0·51	171. Hunder	0·29
113. Nell	0 50	172. Truid air Sgithiche	0·29
114. Fadagoa	0·48	173. Moy	0·29
115. Talla	0·47	174. Gorm Loch Mòr	0·29
116. Morlich	0·47	175. More (Thurso)	0·28
117. Scadavay (East)	0·46	176. Fad	0·28
118. Creagach	0·46	177. Knockie	0·28
119. Skene (Dee)	0·46	178. Drumellie	0·27
120. Grennoch	0·45	179. Pattack	0·27
121. Insh	0·44	180. an Daimh (Shin)	0·27
122. a' Bhealaich (Gairloch)	0·44	181. Maberry	0·27
123. Dhùghaill (Carron)	0·44	182. Benisval	0·27
124. Chon (Forth)	0·43	183. Clubbi Shuns	0·27
125. Loyne (East)	0·43	184. a' Bhealaich (Naver)	0·27
126. Hundland	0·43	185. Turret	0·26
127. Beannachan	0·42	186. Calavie	0·26
128. na h-Earba (West)	0·41	187. Woodhall	0·26
129. Migdale	0·41	188. an Staca	0·26
130. a' Ghriama	0·40	189. Tollie	0·26
131. Cliff	0·40	190. Benachally	0·25
132. Dee	0·40	191. Cròcach	0·25
133. an t-Seilich	0·39	192. Achanalt	0·25
134. Kilbirnie	0·39	193. Bunacharan	0·25
135. Ailsh	0·38	194. Rescobie	0·25
136. Eilde Mòr	0·38	195. Skaill	0·24
137. na Sàlach Uidhre	0·38	196. Clair (Ewe)	0 24
138. Lyon	0·37	197. na Beinne Bàine	0·24
139. More Barvas	0·37	198. Milton	0·24
140. Castle (Bladenoch)	0·36	199. Ochiltree	0·24
141. Shurrery	0·36	200. an Stromore	0·24
142. Mochrum	0·36	201. Loyne (West)	0·24
143. Harperrig	0·35	202. Fada (Gruinard)	0·23
144. Scamadale	0·35	203. Davan	0·23
145. Girlsta	0·35	204. Ghuilbinn	0·23
146. Kirbister	0·35	205. na h-Earba (East)	0·23
147. Lowes (Tay)	0·34	206. Garbhaig	0·23
148. Lungard	0·34	207. Gelly	0·23
149. Hempriggs	0·34	208. Achilty	0·23
150. Spiggie	0·34	209. White (Ryan)	0·23
151. Arklet	0·33	210. Black (Ryan)	0·23
152. Fionn (Kirkaig)	0·33	211. Tankerness	0·23
153. Eye	0·33	212. Inbhir	0·23
154. Allt an Fheàrna	0·33	213. Tralaig	0·23
155. Urrahag	0·33	214. Trool	0·23
156. Castle Semple	0·32	215. Alvie	0·22
157. Achray	0·32	216. Olavat	0·22
158. Dubh (Gruinard)	0·32	217. Drunkie	0·22
159. Meiklie	0·31	218. Gartmorn	0·22
160. Kernsary	0·31	219. Sgamhain	0·22
161. Ussie	0·31	220. Fitty	0·22
162. Scarmclate	0·30	221. Finlas	0·22
163. Castle (Annan)	0·30	222. Dilate	0·22
164. St John's	0 30	223. nam Breac	0·22
165. Threipmuir	0·30	224. Nant	0·22

Table II—*continued*

Loch.	Area. Square Miles.	Loch.	Area. Square Miles.
225. Bad an Sgalaig . .	0·22	284. a' Ghobhainn	0·15
226. Eela	0·22	285. an Tomain . . .	0·15
227. Doine	0·21	286. Dubh (Gairloch) . .	0·15
228. Kindar	0·21	287. na Moracha . . .	0·15
229. Iubhair	0·21	288. an Draine . . .	0·15
230. Huna	0·21	289. Chaluim	0·15
231. Gainmheich (South) . .	0·21	290. Roer	0·15
232. Tarff	0·21	291. Lowes (Tweed) . . .	0·15
233. Clunie (Tay) . . .	0·21	292. Giorra	0·14
234. Strandavat . . .	0·21	293. Peppermill . . .	0·14
235. Vaara	0·21	294. Drummond . . .	0·14
236. Buidhe (Fleet) . . .	0·21	295. Oban nam Fiadh . .	0·14
237. Killin	0·20	296. an Nostarie . . .	0·14
238. Lochrutton . . .	0·20	297. an Tachdaidh . . .	0·14
239. an Eilein (Spey) . .	0·20	298. an Eilein (Gairloch) . .	0·14
240. Skealtar	0·20	299. Braigh Horrisdale . .	0·14
241. na Craobhaig . . .	0·20	300. na Moine	0·14
242. Muckle Water . . .	0·19	301. Poulary	0·14
243. Coire nam Meann . .	0·19	302. Dungeon	0·14
244. Langavat (Benbecula) .	0·19	303. Clings	0·14
245. an Dùin (N. Uist) . .	0·19	304. Bodavat	0·14
246. Skerrow	0·19	305. Stacsavat	0·14
247. a' Bharpa . . .	0·19	306. Broom	0·13
248. Araich-Lin . . .	0·18	307. Bradan	0·13
249. na Cuaich . . .	0·18	308. Isbister	0·13
250. Ordie	0·18	309. Loch	0·13
251. Gryfe	0·18	310. Heouravay . . .	0·13
252. Coulin (Ewe) . . .	0·18	311. Awe (Inver) . . .	0·13
253. a' Chuilinn (Conon) . .	0·18	312. Auchenreoch . . .	0·13
254. Droma	0·18	313. Allt na h-Airbhe . .	0·13
255. Borralan	0·18	314. Crogavat	0·13
256. Martnaham . . .	0·18	315. a' Choire	0·13
257. Beannach (Inver) . .	0·18	316. ic Colla	0·13
258. Daimh (Tay) . . .	0·17	317. an Laghair . . .	0·13
259. Teàrnait	0·17	318. a' Bhuird.	0·13
260. Wester	0·17	319. Dochard	0·13
261. an Gead	0·17	320. na Leitreach . . .	0·13
262. Syre	0·17	321. Crò Criosdaig . . .	0·13
263. Clousta	0·17	322. Kennard	0·12
264. Butterstone . . .	0·17	323. Burga	0·12
265. Sguod	0·17	324. Caol na Doire . . .	0·12
266. a' Bhaid Daraich . .	0·17	325. Builg	0·12
267. Lindores	0·17	326. Stormont	0·12
268. Lundie (Garry) . .	0·17	327. Arthur	0·12
269. Dornal	0·17	328. an t-Slagain . . .	0·12
270. Urr	0·17	329. a' Bhealaich (Alsh) . .	0·12
271. Tingwall	0·17	330. Beannach (Gruinard) .	0·12
272. Derculich	0·16	331. Sabiston	0·12
273. an Duin (Spey) . .	0·16	332. Druim Suardalain . .	0·12
274. Long	0·16	333. Deoravat	0·12
275. Forfar	0·16	334. Monikie (South) . .	0·12
276. Linlithgow . . .	0·16	335. Craiglush	0·11
277. Portmore	0·16	336. Doire nam Mart . .	0·11
278. Whinyeon . . .	0·16	337. Crunachan . . .	0·11
279. Carlingwark . . .	0·16	338. Callater	0·11
280. a' Mhuilinn . . .	0·16	339. Sealbhag	0·11
281. nam Faoileag . . .	0·16	340. Skeen (Annan) . . .	0·11
282. Skiach	0·15	341. an Dùna	0·11
283. Kilconquhar . . .	0·15	342. na h-Airidh Sléibhe . .	0·11

TABLE II—*continued*

Loch.	Area. Square Miles.	Loch.	Area. Square Miles.
343. Ederline	0·11	402. Veiragvat. . . .	0·08
344. an Lagain . . .	0·11	403. Burraland . . .	0·08
345. Lochinvar . . .	0·11	404. Valtos	0·08
346. Kemp	0·11	405. an Droighinn . . .	0·08
347. Soulseat	0·11	406. Rosebery	0·08
348. an Leòid	0·11	407. Balgavies. . . .	0·08
349. Raoinavat . . .	0·11	408. Clickhimin . . .	0·07
350. Bosquoy	0·10	409. Dochart	0·07
351. Con (Tay) . . .	0·10	410. Holl	0·07
352. Hosta	0·10	411. Breaclaich . . .	0·07
353. na h-Ealaidh . . .	0·10	412. Burntisland . . .	0·07
354. na Ceithir Eileana . .	0·10	413. na Lairige . . .	0·07
355. Morsgail	0·10	414. Oban a' Chlachain . .	0·07
356. Liath	0·10	415. Shechernich . . .	0·07
357. an Laig Aird . . .	0·10	416. na Doire Daraich . .	0·07
358. Phitiùlais . . .	0·10	417. Sandy	0·07
359. Raonasgail . . .	0·10	418. nan Gabhar . . .	0·07
360. Littlester. . . .	0·10	419. Bad a' Chrotha . .	0·07
361. Bruadale	0·10	420. a' Chlachain (Lewis) . .	0·07
362. Vatandip	0·10	421. Craggie	0·07
363. Lùnn dà-Bhrà . . .	0·10	422. Whitefield . . .	0·07
364. a' Phearsain . . .	0·10	423. Eldrig	0·07
365. Sloy.	0·10	424. Monikie (North) . .	0·07
366. Cuil Airidh a' Flod . .	0·10	425. Gown (North) . . .	0·07
367. nan Lann . . .	0·10	426. Lochnaw	0·07
368. Eigheach	0·09	427. Dibadale	0·07
369. Spynie	0·09	428. Fleet	0·07
370. Ghuiragarstidh . .	0·09	429. Airidh na Lic . . .	0·07
371. nam Breac Dearga . .	0·09	430. Brow	0·07
372. na Mòine Buige . .	0·09	431. Dhomhnuill Bhig . .	0·07
373. Cuìl na Sìthe . . .	0·09	432. Howie	0·07
374. a' Chlachain (Nairn) .	0·09	433. Hoglinns	0·06
375. Gown (South) . . .	0·09	434. Auchenchapel . . .	0·06
376. Bogton	0·09	435. Dallas	0·06
377. na Sreinge . . .	0·09	436. Monzievaird . . .	0·06
378. Punds	0·09	437. Aboyne	0·06
379. North-house . . .	0·09	438. Hoil	0·06
380. Kirk Dam . . .	0·09	439. Harperleas . . .	0 06
381. nan Deaspoirt . . .	0·09	440. Moraig	0·06
382. Muckle Lunga . . .	0·09	441. Fingask	0·06
383. Aithness	0·09	442. an Iasgaich . . .	0·06
384. na Déighe fo Dheas . .	0·08	443. nan Eun (Tay) . .	0·06
385. Sròn Smeur . . .	0·08	444. Tarruinn an Eithir . .	0·06
386. Hermidale . . .	0·08	445. na Creige Duibhe . .	0·06
387. na Stainge . . .	0·08	446. a' Chonnachair . .	0·06
388. a' Bhradain . . .	0·08	447. Mhic' ille Riabhaich .	0·06
389. Moor Dam . . .	0·08	448. Laide	0·06
390. Leitir Easaich . . .	0·08	449. Dhùgaill (Torridon) . .	0·06
391. Lochaber	0·08	450. Flugarth	0·06
392. a' Mhiotailt . . .	0·08	451. Black (Etive) (East). .	0·06
393. an Tuirc	0·08	452. Harrow	0·06
394. a' Ghlinne Dorcha . .	0·08	453. Derclach	0·06
395. Seil	0·08	454. Crombie Den . . .	0·06
396. White of Myrton . .	0·08	455. Peerie	0·06
397. Ceò-Glas	0·08	456. Airidh na Ceardaich .	0·06
398. Leodsay	0·08	457. Gainmheich (North) .	0·06
399. Scaslavat	0·08	458. na Bì	0·06
400. Tormasad . . .	0·08	459. nan Druimnean . .	0·06
401. Snarravoe . . .	0·08	460. Lochenbreck . . .	0·06

Table II—*continued*

Loch.	Area. Square Miles.	Loch.	Area. Square Miles.
461. Black (Etive) (Mid)	0·05	512. Tilt	0·03
462. ,, ,, (West)	0·05	513. Allan	0·03
463. Buidhe (Tay)	0·05	514. Maol a' Choire	0·03
464. Kinghorn	0·05	515. Tùtach	0·03
465. Essan	0·05	516. Màma	0·03
466. Kirk	0·05	517. Kirriereoch	0·03
467. Bhac	0·05	518. Brough	0·03
468. Mill	0·05	519. Kilchoan (Lower)	0·03
469. Rae	0·05	520. a' Chaoruinn	0·03
470. nan Garbh Chlachain	0·05	521. Hightae Mill	0·03
471. Dubh (Ailort)	0·05	522. Fithie	0·03
472. na Coinnich	0·05	523. Sior	0·03
473. Eileach Mhic' ille Riabhaich	0·05	524. na Beithe	0·03
474. na Garbh-Abhuinn	0·05	525. a' Buaille	0·03
475. na Claise Feàrna	0·05	526. Cults	0·03
476. Baile a' Ghobhainn	0·05	527. na Garbh-Abhuinn Ard	0·03
477. Asta	0·05	528. Skae	0·03
478. a' Bhainne	0·05	529. Aslaich	0·03
479. Harelaw	0·05	530. Dubh (Etive)	0·03
480. Birka	0·05	531. Hostigates	0·03
481. nan Eun (Ness)	0·05	532. Duddingston	0·03
482. an Losgainn Mòr	0·05	533. Pitlyal	0·02
483. Dubh-Mor	0·05	534. Sand	0·02
484. Gleann a' Bhearraidh	0·05	535. White (Tay)	0·02
485. Fiart	0·05	536. an t-Seasgain	0·02
486. Edgelaw	0·05	537. Dubh (Forth)	0·02
487. Grass	0·05	538. a' Chladaich	0·02
488. Lure	0·05	539. Scoly	0·02
489. na Craige	0·04	540. Crann	0·02
490. Blairs	0·04	541. Duartmore	0·02
491. Fender	0·04	542. Kinellan	0·02
492. Anna	0·04	543. na Gealaich	0·02
493. Monk Myre	0·04	544. Cornish	0·02
494. Eion Mhic Alastair	0·04	545. nan Ràth	0·02
495. na Beiste	0·04	546. Setter	0·02
496. nan Geireann	0·04	547. Magillie	0·02
497. Beag	0·04	548. na h' Eaglais	0·02
498. Kilcheran	0·04	549. Black (Tay)	0·01
499. Lundie (Clunie)	0·04	550. nan Aùscot	0·01
500. a' Vullan	0·04	551. Uaine	0·01
501. Gamhna	0·04	552. an Tairbeirt Stuadhaich	0·01
502. Uanagan	0·04	553. Loch on Eilean Subhainn	0·01
503. Collaster	0·04	554. na Creige Léithe	0·01
504. Drumlamford	0·04	555. an Dubh (Lochy)	0·01
505. Fyntalloch	0·04	556. Rainbow	0·01
506. Kilchoan (Upper)	0·04	557. Dubh (Ness)	0·01
507. Ree	0·04	558. Choire na Cloich	0·01
508. Muck	0·04	559. nan Losganan	0·01
509. Geal	0·04	560. St Margaret's	0·01
510. Browster	0·04	561. Dhu (Portsonachan)	0·003
511. Bran	0·04	562. Allt na Mult	0·003

TABLE III

FRESH-WATER LOCHS OF SCOTLAND (SOUNDED BY THE LAKE SURVEY) ARRANGED ACCORDING TO MAXIMUM DEPTH

Loch.	Max. Depth. Feet.	Loch.	Max. Depth. Feet.
1. Morar	1017	54. Scamadale	145
2. Ness	754	55. Fionn (Gruinard)	144
3. Lomond	623	56. Bà (Mull)	144
4. Lochy	531	57. a' Bhaid-Luachraich	143
5. Ericht	512	58. Eck	139
6. Tay	508	59. Ossian	132
7. Katrine	495	60. Lungard	129
8. Rannoch	440	61. Tummel	128
9. Treig	436	62. Laidon	128
10. Shiel	420	63. Veyatie	126
11. Maree	367	64. Clunie (Ness)	123
12. Glass	365	65. Càm	122
13. Arkaig	359	66. na h-Oidhche	121
14. More (Laxford)	316	67. a' Bhaid Daraich	121
15. Awe (Etive)	307	68. Gainmheich (South)	120
16. Earn	287	69. Eilt	119
17. Assynt	282	70. Achilty	119
18. Fannich	282	71. Tralaig	117
19. Quoich	281	72. Arienas	116
20. Morie	270	73. Nell	115
21. Monar	260	74. Dubh-Mòr	114
22. Muick	256	75. na h-Airidh Sléibhe	113
23. Fada (Ewe)	248	76. Garry (Tay)	113
24. Affric	221	77. Bunacharan	113
25. Suainaval	219	78. Vennachar	111
26. na Sheallag	217	79. nan Lann	109
27. Laoghal	217	80. Dhùgaill (Torridon)	108
28. Skinaskink	216	81. Stack	108
29. Garry (Ness)	213	82. Naver	108
30. Damh (Torridon)	206	83. Ard	107
31. Dùn na Seilcheig	205	84. Garve	105
32. Frisa	205	85. an Duin (Spey)	102
33. Mullardoch	197	86. Lyon	100
34. Avich	188	87. an Laghair	100
35. Hope	187	88. Eilde Mòr	100
36. Bad a' Ghaill	180	89. Doon	100
37. Dhùghaill (Carron)	179	90. Insh	100
38. Beannachan	176	91. Voil	98
39. Laggan	174	92. Langavat (Lewis)	98
40. a' Chroisg	168	93. an t-Seilich	98
41. Beinn a' Mheadhoin	167	94. Achray	97
42. Luichart	164	95. Drunkie	97
43. Shin	162	96. Daimh (Tay)	95
44. Beoraid	159	97. Benisval	95
45. an Dithreibh	157	98. Raonasgail	95
46. Lurgain	156	99. Dungeon	94
47. Oich	154	100. a' Mhuilinn	94
48. Dubh (Ailort)	153	101. Garbhaig	93
49. St Mary's	153	102. na Creige Duibhe	93
50. Owskeich	153	103. Clair (Ewe)	93
51. Coir' an Fheàrna	151	104. Kernsary	93
52. Obisary	151	105. Nant	92
53. Lubnaig	146	106. a' Bhealaich (Gairloch)	92

TABLE III—*continued*

Loch.	Max. Depth. Feet.	Loch.	Max. Depth. Feet.
107. Gorm Loch Mòr	91	166. an Eilein (Spey)	66
108. Seil	91	167. Brora	66
109. Mhor	91	168. Doine	65
110. Fionn (Kirkaig)	90	169. Iubhair	65
111. Grunavat	90	170. Benachally	64
112. Tarff	89	171. Bad an Sgalaig	64
113. Dubh (Gruinard)	88	172. a' Ghriama	64
114. na Leitreach	88	173. Loch on Eilean Subhainn	64
115. Baile a' Ghobhainn	88	174. na Meide	63
116. Tollie	86	175. Ken	62
117. Builg	86	176. Freuchie	62
118. Calder	85	177. an Tachdaidh	62
119. na Cuaich	85	178. Raoinavat	61
120. Merkland	85	179. Dibadale	61
121. a' Ghlinne Dorcha	85	180. Tingwall	60
122. Creagach	84	181. Hunder	60
123. Tulla	84	182. a' Choire	60
124. Calavie	84	183. na Moine Buige	60
125. Leven	83	184. Kilcheran	60
126. Scaslavat	82	185. Allt na h-Airbhe	60
127. na h-Earba (West)	81	186. Gainmheich (North)	59
128. Loch	81	187. nan Druimnean	59
129. a' Chlachain (Nairn)	80	188. Lowes (Tweed)	58
130. a' Bhealaich (Naver)	80	189. Lochrutton	58
131. Turret	79	190. Ederline	58
132. an Leòid	79	191. na Beithe	58
133. Fender	78	192. Fiart	58
134. Menteith	77	193. Drumellie	58
135. Edgelaw	77	194. Pattack	58
136. Chon (Forth)	75	195. Aithness	57
137. Knockie	75	196. Ashie	57
138. Eion Mhic Alastair	74	197. Hoglinns	57
139. Phitiùlais	74	198. an Losgainn Mòr	57
140. Girlsta	74	199. Clousta	57
141. Caravat	74	200. Fleet	56
142. a' Bhraoin	73	201. nan Deaspoirt	56
143. Talla	73	202. Sealbhag	56
144. Clings	73	203. Fada (Gruinard)	56
145. Sgamhain	72	204. Skiach	55
146. Kennard	72	205. Trool	55
147. Fiodhaig	71	206. an t-Slagain	55
148. Cròcach	71	207. Liath	55
149. nam Breac	71	208. Rosebery	55
150. Kilchoan (Upper)	70	209. Mill	55
151. Leitir Easaich	70	210. an Draine	55
152. Alvie	70	211. Caol na Doire	55
153. nam Breac Dearga	70	212. Dilate	55
154. Achall	70	213. Lochaber	55
155. Lintrathen	70	214. Crogavat	55
156. Derculich	70	215. Gladhouse	55
157. Clunie (Tay)	69	216. Eela	55
158. a' Mhiotailt	69	217. Lundie (Garry)	54
159. na h-Earba (East)	69	218. Harelaw	54
160. Ordie	69	219. Crombie Den	53
161. Grennoch	68	220. Lowes (Tay)	53
162. Dubh (Gairloch)	68	221. a' Phearsain	53
163. Arklet	67	222. Gown (South)	52
164. Killin	67	223. an Daimh (Shin)	52
165. na Beinne Bàine	67	224. Braigh Horrisdale	51

TABLE III—*continued*

Loch.	Max. Depth. Feet.	Loch.	Max. Depth. Feet.
225. Kemp	51	284. Kindar	41
226. Leum a' Chlamhain	51	285. Gamhna	41
227. an Staca	51	286. Spiggie	41
228. Lochindorb	51	287. White of Myrton	40
229. Moy	50	288. Craggie	40
230. Bran	50	289. Finlas	40
231. Black (Ryan)	50	290. an Dubh (Lochy)	40
232. Inbhir	50	291. Stacsavat	40
233. Arthur	50	292. Urigill	40
234. na Craobhaig	50	293. Monzievaird	39
235. Scadavay (East)	50	294. na Lairige	39
236. nan Eun (Tay)	50	295. Fadagoa	39
237. Giorra	49	296. an Tuirc	39
238. Migdale	49	297. nan Aùscot	39
239. Woodhall	49	298. Howie	39
240. Ghuilbinn	49	299. Burntisland	39
241. Morlich	49	300. Teàrnait	39
242. Coulin (Ewe)	49	301. na Claise Feàrna	38
243. Gleann a' Bhearraidh	48	302. White (Ryan)	38
244. Doire nam Mart	48	303. Fad	38
245. an Droighinn	48	304. Beannach (Inver)	38
246. Fingask	48	305. Holl	38
247. Poulary	47	306. Kinghorn	38
248. Bodavat	46	307. a' Bharpa	37
249. Hoil	46	308. Ghiuragarstidh	37
250. Birka	45	309. Scadavay (West)	37
251. Fada (N. Uist)	45	310. Dee	36
252. Meiklie	45	311. Allt an Fheàrna	36
253. Kilchoan (Lower)	45	312. Buidhe (Fleet)	36
254. Ree	44	313. Black (Etive) (East)	36
255. a' Bhealaich (Alsh)	44	314. Skeen (Annan)	36
256. Màma	44	315. a' Bhuird	36
257. Expansions of River Dee	44	316. Skae	35
258. Craiglush	44	317. Trealaval	35
259. an Tomain	44	318. an Dùin (N. Uist)	35
260. Skebacleit	44	319. na Beiste	35
261. Uanagan	43	320. Loyne (East)	35
262. na Sreinge	43	321. Ussie	35
263. a' Chuilinn (Conon)	43	322. an Nostarie	35
264. na h-Eaglais	43	323. Langavat (Benbecula)	34
265. Dochard	42	324. Gryfe	34
266. Ruthven	42	325. an Eilein (Gairloch)	34
267. Urr	42	326. Ochiltree	34
268. Skealtar	42	327. Auchenreoch	34
269. Thom	42	328. na Déighe fo Dheas	34
270. Baddanloch	42	329. ic Colla	34
271. an Laig Aird	42	330. Coire nam Meann	33
272. Soulseat	42	331. Sròn Smeur	33
273. Bhac	42	332. Eileach Mhic' ille Riabhaich	33
274. na Ceithir Eileana	42	333. Skerrow	33
275. Long	42	334. Whinyeon	33
276. Breaclaich	41	335. Urrahag	33
277. Harperleas	41	336. Roer	32
278. Portmore	41	337. White (Tay)	32
279. Bhradain	41	338. a' Chlàir (Helmsdale)	32
280. Heouravay	41	339. Deoravat	32
281. Dubh (Forth)	41	340. Ceò-Glas	32
282. Hermidale	41	341. Hosta	31
283. Hostigates	41	342. Sloy	31

Table III—*continued*

Loch.	Max. Depth. Feet.	Loch.	Max. Depth. Feet.
343. Druim Suardalain	31	402. Bad a' Chrotha	23
344. nan Eun (N. Uist)	31	403. a' Buaille	23
345. Morsgail	31	404. Muck	23
346. Balgavies	31	405. Airidh na Ceardaich	22
347. Burga	30	406. an Stromore	22
348. Chaluim	30	407. Monikie (North)	22
349. an Gead	30	408. Duartmore	22
350. Bà (Tay)	30	409. nam Faoileag	22
351. Callater	30	410. Black (Etive) (West)	22
352. Harperrig	30	411. Crò Criosdaig	21
353. Punds	30	412. nan Eun (Ness)	21
354. Kilbirnie	30	413. Borralan	21
355. Forfar	29	414. Cliff	21
356. Harrow	29	415. Gartmorn	21
357. Martnaham	29	416. a' Chaoruinn	20
358. Allan	29	417. Leodsay	20
359. an Dùna	29	418. na Moracha	20
360. Snarravoe	29	419. Choire na Cloich	20
361. na Sàlach Uidhre	29	420. na Garbh-Abhuinn	20
362. Beag	29	421. a' Bhaillidh	20
363. Cults	28	422. Muckle Water	20
364. a' Bhainne	28	423. Airidh na Lic	19
365. na h-Achlaise	28	424. Pitlyal	19
366. Eigheach	28	425. Oban a' Chlachain	19
367. nan Cuinne	28	426. Loyne (West)	19
368. Clubbi Shuns	28	427. Essan	18
369. a' Ghobhainn	28	428. Dubh (Ness)	18
370. Black (Etive) (Mid)	27	429. an Lagain	18
371. Valtos	27	430. nan Geireann (Mill)	18
372. nan Geireann	27	431. an t-Seasgain	18
373. Beannach (Gruinard)	27	432. Castle (Annan)	18
374. a' Chonnachair	27	433. Carlingwark	17
375. nan Ràth	27	434. Peppermill	17
376. Anna	27	435. Gown (North)	17
377. a' Vullan	27	436. Stenness	17
378. Linlithgow	27	437. Auchenchapel	17
379. Muckle Lunga	27	438. Crann	17
380. an Ruathair	26	439. Threipmuir	17
381. Aslaich	26	440. Vatandip	17
382. Rainbow	26	441. Swannay	16
383. Monikie (South)	26	442. Rae	16
384. Drumlamford	26	443. Fitty	16
385. na Gealaich	25	444. Droma	16
386. na Coinnich	25	445. Tùtach	16
387. Lùnn dà-Bhrà	25	446. Kinellan	16
388. nan Garbh Chlachain	25	447. an Iasgaich	16
389. Vaara	25	448. Fithie	16
390. Veiragvat	25	449. Lochenbreck	15
391. Kirk	25	450. Milton	15
392. Huna	25	451. Fyntalloch	15
393. Crunachan	25	452. Kirriereoch	15
394. Butterstone	25	453. Moraig	14
395. Lundie (Clunie)	25	454. Whitefield	14
396. Strandavat	25	455. Sguod	14
397. Ailsh	24	456. Cùil na Sìthe	14
398. an Tairbeirt Stuadhaich	24	457. Harray	14
399. Taruinn an Eithir	23	458. Maberry	14
400. Rescobie	23	459. na Stainge	14
401. Geal	23	460. Magillie	14

TABLE III—*continued*

Loch.	Max. Depth. Feet.	Loch.	Max. Depth Feet.
461. na Creige Léithe	14	512. Hempriggs	8
462. na Craige	13	513. Dallas	8
463. Hightae Mill	13	514. na h-Ealaidh	8
464. Asta	13	515. na Moine	8
465. North-house	13	516. Flugarth	8
466. Mochrum	13	517. Black (Tay)	7
467. Strom	13	518. More (Thurso)	7
468. Watten	12	519. Dhomhnuill Bhig	7
469. Truid air Sgithiche	12	520. Cornish	7
470. Olavat	12	521. Eye	7
471. Mhic' ille Riabhaich	12	522. Hundland	7
472. Syre	12	523. Shurrery	7
473. Derclach	12	524. nan Losganan	7
474. Kinord	12	525. Araich-Lin	7
475. Monk Myre	12	526. St John's	7
476. Scoly	12	527. Sandy	7
477. Drummond	12	528. Awe (Inver)	7
478. Castle (Bladenoch)	11	529. na Garbh-Abhuinn Ard	7
479. a' Chlachain (Lewis)	11	530. Tankerness	7
480. Brouster	11	531. Lure	7
481. Dochart	11	532. na Bì	6
482. Aboyne	11	533. Moor Dam	6
483. Dornal	10	534. Kilconquhar	6
484. Uaine	10	535. Grass	6
485. Oban nam Fiadh	10	536. Skene (Dee)	6
486. Dhu (Portsonachan)	10	537. Spynie	6
487. Eldrig	10	538. Lochnaw	6
488. Lindores	10	539. Kirbister	6
489. Peerie	10	540. Bruadale	6
490. Dubh (Etive)	10	541. Brow	6
491. Burraland	10	542. Tilt	5
492. Duddingston	10	543. Blairs	5
493. Clickhimin	10	544. Scarmclate	5
494. Tormasad	10	545. Castle Semple	5
495. Lochinvar	10	546. Heilen	5
496. Collaster	10	547. Bosquoy	5
497. Broom	9	548. nan Gabhar	5
498. Boardhouse	9	549. St Margaret's	5
499. na Doire Daraich	9	550. Kirk Dam	5
500. Davan	9	551. Bogton	4
501. Littlester	9	552. Skaill	4
502. a' Chladaich	9	553. Sand	4
503. Con (Tay)	9	554. Brough	4
504. Cuil Airidh a' Flod	9	555. Sior	4
505. Laide	9	556. Stormont	3
506. Gelly	9	557. Allt na Mult	3
507. Achanalt	9	558. Sabiston	3
508. Shechernich	8	559. Wester	3
509. More Barvas	8	560. Isbister	3
510. Maol a' Choire	8	561. Buidhe (Tay)	3
511. Bradan	8	562. Setter	2

TABLE IV

Fresh-water Lochs of Scotland (sounded by the Lake Survey) arranged according to Mean Depth

Loch.	Mean Depth. Feet.	Loch.	Mean Depth. Feet.
1. Ness	433·02	53. a' Bhaid Daraich	55·60
2. Morar	284·00	54. na h-Oidhche	53·95
3. Lochy	228·95	55. Achilty	51·78
4. Treig	207·37	56. Shin	51·04
5. Katrine	199·19	57. Dubh-Mòr	50·93
6. Tay	199·08	58. Eck	50·16
7. Ericht	189·21	59. Bunacharan	50·11
8. Rannoch	167·46	60. Clunie (Ness)	49·98
9. Glass	159·07	61. Garry (Tay)	49·91
10. Arkaig	152·71	62. Tummel	48·03
11. Earn	137·83	63. Bà (Mull)	47·42
12. Shiel	132·73	64. Eilde Mòr	47·01
13. More (Laxford)	125·83	65. Owskeich	46·90
14. Maree	125·30	66. Lyon	44·87
15. Morie	125·20	67. na h-Airidh Sléibhe	44·43
16. Lomond	121·29	68. Ard	43·86
17. Muick	116·30	69. Garve	43·60
18. Fannich	108·76	70. Lubnaig	42·77
19. Suainaval	108·60	71. Ossian	42·75
20. Awe (Etive)	104·95	72. na Cuaich	42·48
21. Quoich	104·60	73. Vennachar	42·41
22. na Sheallag	103·47	74. Dubh (Gruinard)	42·33
23. Fada (Ewe)	102·20	75. Clair (Ewe)	42·10
24. Assynt	101·10	76. Gainmheich (South)	41·80
25. Avich	98·42	77. Oich	41·78
26. Monar	98·33	78. an t-Seilich	41·30
27. Affric	93·64	79. Tralaig	41·03
28. Dùn na Seilcheig	84·00	80. Veyatie	41·00
29. Garry (Ness)	78·00	81. Voil	40·94
30. Mullardoch	77·52	82. na Leitreach	40·29
31. Frisa	76·40	83. Eion Mhic Alastair	39·73
32. a' Chroisg	73·78	84. Daimh (Tay)	39·12
33. St Mary's	72·93	85. Naver	39·06
34. Beoraid	72·34	86. Baile a' Ghobhainn	38·77
35. Beannachan	70·42	87. Dhùgaill (Torridon)	38·27
36. Scamadale	69 58	88. Kernsary	38·17
37. Laggan	67·68	89. Tulla	38·08
38. Luichart	66·84	90. Calavie	37·91
39. Dhùghaill (Carron)	66·65	91. Càm	37·70
40. an Dithreibh	65·93	92. Insh	37·31
41. Beinn a' Mheadhoin	65·36	93. an Laghair	37·23
42. Laoghal	65·21	94. Eilt	37·12
43. Lungard	63·68	95. nan Lann	37·03
44. Dubh (Ailort)	62·70	96. Nell	36·80
45. Bad a' Ghaill	61·90	97. Seil	36·73
46. Hope	61·47	98. a' Bhraoin	36·60
47. Lurgain	60·90	99. Lowes (Tweed)	36·55
48. Skinaskink	60·40	100. Drunkie	36·05
49. Damh (Torridon)	58·91	101. Achray	36·01
50. Coir' an Fheàrna	58·79	102. Stack	35·91
51. Fionn (Gruinard)	57·79	103. an Leòid	35·75
52. Arienas	56·60	104. na h-Earba (West)	35·62

TABLE IV—*continued*

Loch.	Mean Depth. Feet.	Loch.	Mean Depth. Feet.
105. Garbhaig	35·41	163. Benachally	25·06
106. Laidon	35·19	164. Iubhair	24·96
107. Talla	34·70	165. Langavat (Lewis)	24·79
108. Benisval	34·68	166. Derculich	24·72
109. Scaslavat	34·65	167. Crogavat	24·66
110. a' Mhuilinn	34·15	168. na Mòine Buige	24·62
111. a' Bhaid-Luachraich	34·02	169. Gainmheich (North)	24·50
112. Creagach	33·17	170. nam Breac Dearga	24·43
113. Doine	33·13	171. Knockie	24·40
114. Tollie	33·13	172. Nant	24·31
115. a' Bhealaich (Gairloch)	32·74	173. Gorm Loch Mòr	24·30
116. na Creige Duibhe	32·49	174. Arklet	24·19
117. Raonasgail	32·37	175. Killin	24·15
118. Kennard	32·27	176. Mhor	24·11
119. Turret	31·79	177. Tarff	23·89
120. Fender	31·77	178. Dilate	23·50
121. Dubh (Gairloch)	31·74	179. Lintrathen	23·42
122. Girlsta	31·41	180. Black (Ryan)	23·37
123. a' Bhealaich (Naver)	31·20	181. Ederline	23·15
124. na h-Earba (East)	31·11	182. Phitiùlais	23·15
125. Edgelaw	31·10	183. Fiart	23·13
126. an Duin (Spey)	30·38	184. Caol na Doire	23·04
127. a' Mhiotailt	30·30	185. na h-Eaglais	22·84
128. Allt na h-Airbhe	30·17	186. Fingask	22·83
129. Merkland	30·14	187. Freuchie	22·83
130. a' Chlachain (Nairn)	29·84	188. Harelaw	22·83
131. Loch on Eilean Subhainn	29·70	189. Brora	22·68
132. Kilchoan (Upper)	29·54	190. Dungeon	22·64
133. Chon (Forth)	29·38	191. Liath	22·36
134. Loch	29·22	192. Meiklie	22·10
135. Drumellie	29·18	193. Fleet	21·81
136. Clunie (Tay)	29·12	194. Giorra	21·70
137. Grunavat	28·36	195. nan Eun (Tay)	21·64
138. na Beinne Bàine	28·33	196. Doire nam Mart	21·33
139. a' Ghriama	28·03	197. Ashie	21·26
140. nam Breac	27·94	198. Migdale	21·18
141. Achall	27·83	199. Kilcheran	21·11
142. Dibadale	27·77	200. Ken	21·00
143. Builg	27·75	201. Calder	20·87
144. na Beithe	27·72	202. nan Deaspoirt	20·82
145. a' Ghlinne Dorcha	27·65	203. Grennoch	20·82
146. a' Choire	27·55	204. Dubh (Forth)	20·70
147. an Daimh (Shin)	27·17	205. Sealbhag	20·66
148. Alvie	27·02	206. na Meide	20·61
149. Sgamhain	26·77	207. Lochaber	20·57
150. Doon	26·71	208. Raoinavat	20·56
151. Clings	26·55	209. Fionn	20·40
152. Ordie	26·32	210. Lowes (Tay)	20·40
153. Kemp	26·23	211. Kilchoan (Lower)	20·30
154. Hoglinns	26·09	212. Leitir Easaich	19·90
155. an Drainc	25·86	213. Menteith	19·77
156. Fiodhaig	25·79	214. Woodhall	19·67
157. Arthur	25·77	215. Leum a' Chlamhain	19·54
158. Obisary	25·70	216. a' Phearsain	19·44
159. an Eilein (Spey)	25·47	217. Moy	19·31
160. Mill	25·33	218. Thom	19·25
161. Bad an Sgalaig	25·26	219. Hoil	19·09
162. Rosebery	25·20	220. Tingwall	18·88

Table IV—*continued*

Loch.	Mean Depth. Feet.	Loch.	Mean Depth. Feet.
221. Aithness	18·84	279. Eileach Mhic'ille Riabhaich	14·13
222. an Losgainn Mòr . .	18·65	280. Breaclaich . . .	14·09
223. Trool	18·39	281. White (Ryan) . . .	14·09
224. Coulin (Ewe) . . .	18·29	282. Pattack	14·07
225. Braigh Horrisdale . .	18·10	283. Expansions of River Dee .	13·90
226. Skiach	18·09	284. na Ceithir Eileana . .	13·81
227. Hunder	18·08	285. White of Myrton . .	13·70
228. Harperleas	17·88	286. a' Chlàir (Helmsdale) .	13·65
229. an Tachdaidh	17·88	287. Monikie (South) . .	13·47
230. Skeen (Annan)	17·87	288. Vaara	13·44
231. Crombie Den	17·64	289. Black (Etive) (East) . .	13·39
232. na Sreinge	17·53	290. an Ruathair . . .	13·34
233. Stacsavat	17·43	291. Ghuilbinn . . .	13·32
234. Gryfe	17·35	292. na Claise Feàrna . .	13·23
235. Baddanloch	17·33	293. Beannach (Inver) . .	13·20
236. Fada (Gruinard) . .	17·15	294. an Dùna	13·12
237. Fad	17·13	295. Urigill	13·10
238. Holl	17·04	296. Lochrutton	13·03
239. Cròcach	16·80	297. White (Tay) . . .	12·95
240. Uanagan	16·80	298. Gleann a' Bhearraidh .	12·79
241. nan Aùscot	16·79	299. Anna	12·74
242. Portmore	16·79	300. Burga	12·65
243. na Craobhaig	16·63	301. Bran	12·63
244. Eela	16·59	302. Skerrow	12·63
245. Caravat	16·57	303. Bodavat	12·61
246. a' Bhealaich (Alsh) . .	16·53	304 a' Ghobhainn	12·59
247. Bhac	16·50	305. Monikie (North) . .	12·58
248. an Tomain	16·47	306. Snarravoe	12·55
249. Gladhouse	16·46	307. Hermidale	12·49
250. an t-Slagain	16·42	308. Hosta	12·47
251. Lundie (Garry) . .	16·28	309. a' Bharpa	12·43
252. Hostigates	16·26	310. Lochindorb	12·42
253. Teàrnait	16·16	311. nan Cuinne	12·38
254. Craiglush	16·13	312. Morsgail	12·33
255. Skealtar	15·90	313. a' Vullan	12·27
256. Gown (South) . . .	15·88	314. Whinyeon	12·22
257. Howie	15·69	315. Urr	12·06
258. nan Druimnean . .	15·61	316. Callater	11·99
259. an Staca	15·52	317. Burntisland . . .	11·85
260. an Dubh (Lochy) . .	15·50	318. Dochard	11·84
261. Kinghorn	15·33	319. Birka	11·81
262. Craggie	15·31	320. Beag	11·80
263. Clousta	15·27	321. Buidhe (Fleet) . . .	11·72
264. Skebacleit	15·21	322. Fadagoa	11·70
265. Soulseat	15·19	323. Auchenreoch . . .	11·69
266. an Laig Aird . . .	15·12	324. Harrow	11·61
267. Ree	14·96	325. Coire nam Meann . .	11·60
268 Leven	14·87	326. Deoravat	11·60
269. Bhradain	14·83	327. Spiggie	11·59
270. an Droighinn . . .	14·78	328. Urrahag	11·49
271. Monzievaird . . .	14·70	329. Forfar	11·43
272. Morlich	14·62	330. an Gead	11·29
273. an Eilein (Gairloch) . .	14·39	331. Butterstone . . .	11·29
274. Rainbow	14·33	332. Black (Etive) (Mid) . .	11·27
275. Allt an Fheàrna . .	14·31	333. Ruthven	11·27
276. Màma	14·29	334. Muckle Water . . .	11·08
277. Dee	14·25	335. na Lairige . . .	10·97
278. Kindar	14·22	336. Harperrig . . .	10·96

TABLE IV—*continued*

Loch.	Mean Depth. Feet.	Loch.	Mean Depth. Feet.
337. an Nostarie	10·95	395. Peppermill	8·60
338. Aslaich	10·91	396. Castle (Annan)	8·58
339. Drumlamford	10·82	397. nan Geireann	8·47
340. ic Colla	10·77	398. Lùnn dà-Bhrà	8·44
341. Gartmorn	10·75	399. Watten	8·42
342. Cliff	10·65	400. Pitlyal	8·32
343. an Tuirc	10·60	401. Ailsh	8·30
344. na Beiste	10·56	402. Auchenchapel	8·26
345. na Déighe fo Dheas	10·54	403. nan Ràth	8·23
346. an Tairbeirt Stuadhaich	10·50	404. Huna	8·22
347. Stenness	10·43	405. Langavat (Benbecula)	8·12
348. a' Bhuird	10·42	406. Sloy	8·12
349. Allan	10·40	407. Bà (Tay)	8·10
350. Geal	10·38	408. Whitefield	8·01
351. Loyne (East)	10·32	409. Ussie	7·98
352. Sròn Smeur	10·31	410. Chaluim	7·92
353. Druim Suardalain	10·30	411. Threipmuir	7·90
354. Fada (N. Uist)	10·25	412. Inbhir	7·85
355. a' Chuilinn (Conon)	10·22	413. nan Eun (N. Uist)	7·84
356. Punds	10·20	414. Lundie (Clunie)	7·80
357. Roer	10·16	415. Crunachan	7·79
358. Ceò-Glas	10·14	416. Ochiltree	7·68
359. Rescobie	9·99	417. Lochenbreck	7·61
360. Kirk	9·96	418. a' Bhaillidh	7·60
361. na Gealaich	9·94	419. an Lagain	7·57
362. Long	9·92	420. Linlithgow	7·55
363. nan Eun (Ness)	9·90	421. Fyntalloch	7·48
364. Poulary	9·90	422. na Craige	7·42
365. Vatandip	9·85	423. Cùil na Sìthe	7·42
366. Balgavies	9·76	424. Derclach	7·42
367. Oban a' Chlachain	9·75	425. Fithie	7·42
368. Kilbirnie	9·72	426. Fitty	7·40
369. a' Bhainne	9·69	427. Valtos	7·40
370. Finlas	9·69	428. Leodsay	7·38
371. Martnaham	9·61	429. Heouravay	7·37
372. Borralan	9·60	430. Black (Etive) (West)	7·34
373. na h-Achlaise	9·58	431. Maberry	7·32
374. Gamhna	9·56	432. Hightae Mill	7·31
375. Skae	9·52	433. nan Garbh Chlachain	7·28
376. Choire na Cloich	9·44	434. Kinellan	7·14
377. a' Chaoruinn	9·37	435. Muck	7·12
378. na Moracha	9·26	436. Dubh (Ness)	7·00
379. Swannay	9·22	437. na Creige Léithe	7·00
380. Trealaval	9·22	438. Strom	7·00
381. Airidh na Lic	9·21	439. Kirriereoch	6·98
382. Cults	9·16	440. Sguod	6·91
383. Scadavay (West)	9·16	441. Muckle Lunga	6·88
384. Ghiuragarstidh	9·08	442. Gown (North)	6·87
385. Harray	9·02	443. Carlingwark	6·86
386. an Stromore	9·01	444. a' Buaille	6·82
387. a' Chonnachair	8·88	445. Essan	6·82
388. Clubbi Shuns	8·85	446. Crann	6·79
389. Crò Criosdaig	8·80	447. Mochrum	6·75
390. nam Faoileag	8·69	448. Milton	6·67
391. Veiragvat	8·68	449. North-house	6·60
392. Scadavay (East)	8·67	450. Rae	6·59
393. na Coinnich	8·62	451. Castle (Bladenoch)	6·56
394. Strandavat	8·61	452. na Sàlach Uidhre	6·54

TABLE IV—*continued*

Loch.	Mean Depth. Feet.	Loch.	Mean Depth. Feet.
453. Beannach (Gruinard)	6·45	508. Achanalt	4·50
454. Lochinvar	6·41	509. a' Chladaich	4·50
455. nan Geireann (Mill)	6·37	510. Cuil Airidh a' Flod	4·50
456. Tarruin an Eithir	6·37	511. St John's	4·50
457. Peerie	6·34	512. Bruadale	4·46
458. an Dùin (N. Uist)	6·27	513. Araich-Lin	4·45
459. Droma	6·27	514. Bradan	4·40
460. Eigheach	6·09	515. Shurrery	4·37
461. Bad a' Chrotha	6·08	516. Tankerness	4·35
462. Boardhouse	6·06	517. More Barvas	4·33
463. Aboyne	6·03	518. Hundland	4·32
464. Loyne (West)	5·93	519. Lochnaw	4·32
465. Duartmore	5·90	520. Oban nam Fiadh	4·23
466. Collaster	5·88	521. Olavat	4·20
467. Airidh na Ceardaich	5·86	522. More (Thurso)	4·18
468. Truid air Sgithiche	5·83	523. Kirbister	4·15
469. an t-Seasgain	5·72	524. Eye	4·06
470. Scoly	5·72	525. Shechernich	4·01
471. Eldrig	5·70	526. Davan	3·98
472. Clickhimin	5·60	527. Dhomhnuill Bhig	3·90
473. Tormasad	5·60	528. Lure	3·90
474. Brouster	5·57	529. Kilconquhar	3·90
475. an Iasgaich	5·55	530. Cornish	3·80
476. Moraig	5·54	531. na Doire Daraich	3·60
477. a' Chlachain (Lewis)	5·52	532. Dallas	3·50
478. Syre	5·48	533. nan Losganan	3·50
479. Magillie	5·37	534. Uaine	3·50
480. Dornal	5·36	535. Con (Tay)	3·47
481. Mhic' ille Riabhaich	5·35	536. na Bì	3·30
482. Flugarth	5·23	537. Moor Dam	3·27
483. Hempriggs	5·22	538. na Garbh-Abhuinn Ard	3·02
484. Laide	5·16	539. Grass	2·99
485. Duddingston	5·14	540. Dubh (Etive)	2·76
486. Asta	5·11	541. Spynie	2·71
487. Maol a' Choire	5·10	542. Blairs	2·55
488. na Stainge	5·10	543. Brow	2·50
489. Drummond	5·09	544. Bosquoy	2·50
490. Monk Myre	5·08	545. Castle Semple	2·50
491. Lindores	5·06	546. Heilen	2·50
492. Gelly	5·03	547. nan Gabhar	2·50
493. Kinord	5·03	548. St Margaret's	2·50
494. Dochart	5·02	549. Scarmclate	2·50
495. Broom	5·02	550. Tilt	2·50
496. Dhu (Portsonachan)	5·00	551. Bogton	2·00
497. Kirk Dam	5·00	552. Brough	2·00
498. Tùtach	4·88	553. Sand	2·00
499. Awe (Inver)	4·80	554. Sior	2·00
500. Sandy	4·76	555. Skaill	2·00
501. Black (Tay)	4·73	556. Allt na Mult	1·50
502. Skene (Dee)	4·69	557. Buidhe (Tay)	1·50
503. Burraland	4·67	558. Isbister	1·50
504. na h-Ealaidh	4·66	559. Sabiston	1·50
505. na Garbh-Abhuinn	4·65	560. Stormont	1·50
506. na Moine	4·61	561. Wester	1·50
507. Littlester	4·55	562. Setter	1·00

TABLE V

Fresh-water Lochs of Scotland (sounded by the Lake Survey) arranged according to Volume of Water

Loch.	Volume in Million Cubic Feet.	Loch.	Volume in Million Cubic Feet.
1. Ness	263,162	53. Doon	1,517
2. Lomond	92,805	54. Beinn a' Mheadhoin	1,435
3. Morar	81,482	55. an Dithreibh	1,366
4. Tay	56,550	56. Tummel	1,317
5. Awe (Etive)	43,451	57. Ossian	1,224
6. Maree	38,539	58. Tulla	1,167
7. Ericht	38,027	59. Beoraid	1,156
8. Lochy	37,726	60. Ard	1,150
9. Rannoch	34,387	61. Lubnaig	1,144
10. Shiel	27,986	62. Mhor	1,134
11. Katrine	27,274	63. Càm	1,063
12. Arkaig	26,573	64. Veyatie	1,062
13. Earn	14,421	65. Arienas	1,035
14. Treig	13,907	66. Voil	1,000
15. Shin	12,380	67. Stack	988
16. Fannich	10,920	68. Harray	951
17. Assynt	8,731	69. Oich	890
18. Quoich	8,345	70. Garry (Tay)	846
19. Glass	8,265	71. Owskeich	846
20. Fionn (Gruinard)	5,667	72. Obisary	837
21. Laggan	5,601	73. Dhùghaill (Carron)	823
22. More (Laxford)	4,928	74. Beannachan	819
23. Laoghal	4,628	75. na h-Oidhche	816
24. Dùn na Seilcheig	4,599	76. Ken	792
25. Fada (Ewe)	4,091	77. Calder	767
26. Hope	4,032	78. Garve	721
27. na Sheallag	3,948	79. Stenness	716
28. Garry (Ness)	3,794	80. Eilt	686
29. Frisa	3,603	81. Scamadale	685
30. Skinaskink	3,518	82. a' Bhraoin	669
31. Avich	3,327	83. Lungard	599
32. Luichart	3,288	84. Merkland	577
33. Monar	3,213	85. Menteith	562
34. Morie	3,201	86. Brora	553
35. Suainaval	2,843	87. Nell	515
36. Muick	2,771	88. na Meide	498
37. Mullardoch	2,553	89. Eilde Mòr	493
38. Naver	2,461	90. a' Bhaid-Luachraich	486
39. Langavat (Lewis)	2,388	91. Baddanloch	479
40. Eck	2,381	92. Grunavat	478
41. Leven	2,195	93. Lyon	461
42. Damh (Torridon)	2,183	94. Insh	454
43. Affric	2,146	95. an t-Seilich	448
44. Lurgain	2,140	96. a' Chlàir (Helmsdale)	446
45. a' Chroisg	2,057	97. Talla	443
46. St Mary's	2,018	98. Creagach	429
47. Vennachar	1,903	99. Fiodhaig	415
48. Coir' an Fheàrna	1,886	100. na h-Earba (West)	408
49. Bad a' Ghaill	1,768	101. Lintrathen	405
50. Laidon	1,762	102. Achall	401
51. Bà (Mull)	1,602	103. a' Bhealaich (Gairloch)	398
52. Clunie (Ness)	1,533	104. nan Cuinne	396

TABLE V—*continued*

Loch.	Volume in Million Cubic Feet.	Loch.	Volume in Million Cubic Feet.
105. Dubh (Gruinard) . .	374	162. Lowes (Tweed) . .	157
106. Chon (Forth) . . .	358	163. Moy	157
107. Freuchie	347	164. Fadagoa	156
108. Bunacharan . . .	343	165. Trealaval . . .	156
109. Watten	341	166. Bad an Sgalaig . .	151
110. Kernsary . . .	333	167. a' Mhuilinn . . .	150
111. Achilty	332	168. Boardhouse . . .	150
112. Achray	321	169. Black (Ryan) . . .	149
113. a' Ghriama . . .	314	170. Cròcach	148
114. Ashie	309	171. Nant	148
115. Girlsta	308	172. Iubhair	147
116. Scadavay (West) . .	306	173. na Leitreach . . .	147
117. an Ruathair . . .	304	174. Hunder	146
118. Leum a' Chlamhain . .	298	175. Dilate	145
119. Lochindorb . . .	291	176. an Eilein (Spey) . .	144
120. Clair (Ewe) . . .	287	177. Woodhall . . .	144
121. Urigill	285	178. Killin	137
122. Thom	277	179. Dubh (Gairloch) . .	136
123. Calavie	276	180. Tarff	136
124. a' Bhaid Daraich . .	270	181. an Laghair . . .	135
125. Caravat	270	182. an Duin (Spey) . .	134
126. Gladhouse . . .	269	183. Ordie	133
127. Tralaig	267	184. Allt an Fheàrna . .	132
128. Grennoch . . .	263	185. Fad	132
129. Expansions of River Dee .	261	186. na h-Airidh Sléibhe . .	131
130. Benisval	260	187. Skebacleit . . .	128
131. Gainmheich (South) . .	246	188. Loyne (East) . . .	123
132. Tollie	244	189. nan Geireann (Mill) . .	121
133. Migdale	242	190. Cliff	118
134. Swannay . . .	242	191. Trool	116
135. a' Bhealaich (Naver) .	238	192. an Leòid	114
136. Garbhaig . . .	228	193. nan Eun (N. Uist) . .	114
137. Turret	222	194. Scadavay (East) . .	112
138. Arklet	222	195. Spiggie	111
139. Drumellie . . .	222	196. Allt na h-Airbhe . .	110
140. Drunkie	217	197. an Staca	110
141. na Cuaich . . .	214	198. Fada (Gruinard) . .	109
142. Bà (Tay)	206	199. an Draine . . .	108
143. an Daimh (Shin) . .	205	200. Derculich . . .	108
144. Fada (N. Uist) . .	199	201. Harperrig . . .	108
145. Doine	196	202. Kennard	108
146. Gorm Loch Mòr . .	196	203. Pattack	106
147. Knockie	194	204. Kilbirnie . . .	105
148. Lowes (Tay) . . .	194	205. nan Lann . . .	105
149. Meiklie	193	206. Urrahag	105
150. Morlich	192	207. a' Choire . . .	103
151. na h-Earba (East) . .	191	208. Eela	103
152. Daimh (Tay) . . .	190	209. Loch	103
153. na Beinne Bàine . .	190	210. Clings	101
154. Fionn (Kirkaig) . .	186	211. Strom	101
155. Ruthven	180	212. Raonasgail . . .	94
156. Benachally . . .	178	213. Builg	93
157. nam Breac . . .	172	214. na Craobhaig . . .	93
158. Clunie (Tay) . . .	170	215. White (Ryan) . . .	92
159. Sgamhain . . .	165	216. Coulin (Ewe) . . .	90
160. Alvie	163	217. Crogavat . . .	90
161. Dee	157	218. Skealtar . . .	90

Table V—*continued*

Loch.	Volume in Million Cubic Feet.	Loch.	Volume in Million Cubic Feet.
219. Ailsh	88	276. Muckle Water	57
220. Dubh (Ailort)	87	277. a' Bhealaich (Alsh)	56
221. Dungeon	87	278. Maberry	56
222. Gryfe	87	279. Whinyeon	56
223. Tingwall	87	280. Urr	56
224. Ghuilbinn	85	281. an t-Slagain	55
225. Giorra	84	282. Baile a' Ghobhainn	55
226. Arthur	83	283. a' Ghobhainn	54
227. Kindar	83	284. an Gead	54
228. Vaara	80	285. Butterstone	53
229. Seil	79	286. Skeen (Annan)	53
230. a' Chlachain (Nairn)	78	287. a' Phearsain	52
231. Lundie (Garry)	78	288. na Creige Duibhe	52
232. Caol na Doire	77	289. Ochiltree	52
233. Kemp	77	290. Dibadale	51
234. Skiach	77	291. Forfar	51
235. na h-Achlaise	76	292. Hundland	51
236. Portmore	76	293. a' Chuilinn (Conon)	50
237. Teàrnait	75	294. Bodavat	50
238. Lochrutton	73	295. Inbhir	50
239. Scaslavat	73	296. nan Deaspoirt	50
240. an Tachdaidh	72	297. Borralan	49
241. Castle (Annan)	72	298. Craiglush	49
242. Clousta	71	299. Hempriggs	49
243. Ederline	70	300. Strandavat	49
244. na Sàlach Uidhre	70	301. Huna	48
245. a' Mhiotailt	69	302. Edgelaw	47
246. an Tomain	69	303. Lochaber	47
247. Rescobie	69	304. Martnaham	47
248. Buidhe (Fleet)	68	305. Soulseat	47
249. Mochrum	68	306. Truid air Sgithiche	47
250. Skerrow	68	307. Aithness	46
251. Ussie	68	308. Fitty	46
252. Beannach (Inver)	67	309. Eion Mhic Alastair	45
253. Doire nam Mart	67	310. Leitir Easaich	45
254. Phitiùlais	67	311. Milton	45
255. a' Bharpa	66	312. More Barvas	45
256. Dubh-Mòr	66	313. an Laig Aird	44
257. Stacsavat	66	314. an Nostarie	44
258. Threipmuir	66	315. Auchenreoch	44
259. Castle (Bladenoch)	65	316. Dochard	44
260. Gartmorn	65	317. Hoglinns	44
261. Raoinavat	65	318. Langavat (Benbecula)	44
262. Dhùgaill (Torridon)	63	319. Burga	43
263. Braigh Horrisdale	62	320. Gainmheich (North)	43
264. Liath	62	321. Monikie (South)	43
265. a' Bhaillidh	61	322. na Sreinge	43
266. an Stromore	61	323. Roer	43
267. Sealbhag	61	324. Shurrery	43
268. a' Ghlinne-Dorcha	60	325. an Dùna	41
269. Coire nam Meann	60	326. Fleet	41
270. nam Breac Dearga	60	327. Kinord	41
271. Skene (Dee)	60	328. Kirbister	41
272. na Mòine Buige	59	329. Loyne (West)	40
273. an Eilein (Gairloch)	58	330. na Moracha	39
274. Finlas	58	331. Poulary	39
275. Rosebery	58	332. Callater	38

TABLE V—*continued*

Loch.	Volume in Million Cubic Feet.	Loch.	Volume in Million Cubic Feet.
333. Deoravat . . .	38	390. Monzievaird . . .	24
334. Gown (South) . . .	38	391. na Déighe fo Dheas . .	24
335. ic Colla	38	392. an Lagain . . .	23
336. na Ceithir Eileana . .	38	393. Araich-Lin . . .	23
337. nam Faoileag . . .	38	394. Crunachan . . .	23
338. St John's . . .	38	395. Ghuiragarstidh . .	23
339. a' Bhuird . . .	37	396. Lùnn dà-Bhrà . . .	23
340. Eye	37	397. na Beithe . . .	23
341. Hosta	36	398. na Lairige . . .	23
342. Mill	36	399. Sloy	23
343. Druim Suardalain . .	35	400. Sròn Smeur . . .	23
344. Morsgail	35	401. Balgavies . . .	22
345. an Dùin (N. Uist) . .	34	402. Beannach (Gruinard) .	22
346. Bhradain . . .	34	403. Bhac	22
347. Fiart	34	404. Burntisland . . .	22
348. Linlithgow . . .	34	405. Castle Semple . . .	22
349. nan Eun (Tay) . .	34	406. Black (Etive) (East) . .	21
350. Peppermill . . .	34	407. Heilen	21
351. Chaluim	33	408. Scarmclate . . .	21
352. Holl	33	409. Drummond . . .	20
353. an Droighinn . . .	32	410. Kinghorn . . .	20
354. Droma	32	411. na Claise Feàrna . .	20
355. Fingask	32	412. Oban a' Chlachain . .	20
356. Gelly	32	413. Veiragvat . . .	20
357. Long	32	414. Airidh na Lic . . .	19
358. More (Thurso) . .	32	415. Broom	19
359. Sguod	32	416. Cùil na Sìthe . . .	19
360. Achanalt . . .	31	417. Eileach Mhic'ille Riabhaich	19
361. Carlingwark . . .	31	418. Harrow	19
362. Crò Criosdaig . . .	31	419. Lochinvar . . .	19
363. Crombie Den . . .	31	420. Awe (Inver) . . .	18
364. Fender	31	421. na Moine . . .	18
365. Harperleas . . .	31	422. Uanagan . . .	18
366. Howie	31	423. Black (Etive) (Mid) . .	17
367. White of Myrton . .	30	424. Muckle Lunga . . .	17
368. Craggie	30	425. Oban nam Fiadh . .	17
369. Harelaw	30	426. Ree	17
370. Hermidale . . .	29	427. Whitefield . . .	16
371. Hoil	29	428. Bradan	16
372. Kilchoan (Upper) . .	29	429. Eigheach . . .	16
373. Tankerness . . .	28	430. Gleann a' Bhearraidh .	16
374. an Losgainn Mòr . .	27	431. Kilchoan (Lower) . .	16
375. Breaclaich . . .	27	432. Kilconquhar . . .	16
376. Snarravoe . . .	27	433. Leodsay . . .	16
377. Vatandip . . .	27	434. North-house . . .	16
378. Dornal	26	435. Valtos	16
379. Heouravay . . .	26	436. a' Chonnachair . .	15
380. Kilcheran . . .	26	437. a' Vullan . . .	15
381. Monikie (North) . .	26	438. Birka	15
382. nan Druimnean . .	26	439. Kirk	15
383. Olavat	26	440. nan Eun (Ness) . .	15
384. Punds	26	441. a' Bhainne . . .	14
385. an Tuirc	25	442. Gown (North) . . .	14
386. Davan	25	443. Anna	13
387. Syre	25	444. Beag	13
388. Ceò-Glas	24	445. Bran	13
389. Lindores	24	446. Bruadale . . .	13

Table V—*continued*

Loch.	Volume in Million Cubic Feet.	Loch.	Volume in Million Cubic Feet.
447. Drumlamford	13	505. na Doire Daraich	7
448. Hostigates	13	506. na Gealaich	7
449. Littlester	13	507. Shechernich	7
450. Lochenbreck	13	508. Spynie	7
451. na h-Ealaidh	13	509. Wester	7
452. Skaill	13	510. a' Buaille	6
453. Auchenchapel	13	511. an Dubh (Lochy)	6
454. Bad a' Chrotha	12	512. Dallas	6
455. Cuil Airidh a' Flod	12	513. Hightae Mill	6
456. Derclach	12	514. na Bì	6
457. Geal	12	515. na Garbh-Abhuinn	6
458. Kirk Dam	12	516. nan Aùscot	6
459. na Coinnich	12	517. Monk Myre	6
460. Tormasad	12	518. Loch on Eilean Subhainn	6
461. a' Chlachain (Lewis)	11	519. Bogton	5
462. Burraland	11	520. Brouster	5
463. Clickhimin	11	521. Brow	5
464. Eldrig	11	522. Isbister	5
465. Màma	11	523. Kinellan	5
466. na Beiste	11	524. Kirriereoch	5
467. na Stainge	11	525. Lure	5
468. nan Garbh Chlachain	11	526. nan Gabhar	5
469. Peerie	11	527. nan Ràth	5
470. Aboyne	10	528. Pitlyal	5
471. Allan	10	529. Sabiston	5
472. Aslaich	10	530. Stormont	5
473. Black (Etive) (West)	10	531. an t-Seasgain	4
474. Con (Tay)	10	532. Crann	4
475. Dochart	10	533. Duddingston	4
476. Essan	10	534. Grass	4
477. Gamhna	10	535. Maol a' Choire	4
478. na h-Eaglais	10	536. Tùtach	4
479. nan Geireann	10	537. Blairs	3
480. Tarruinn an Eithir	10	538. Cornish	3
481. Airidh na Ceardaich	9	539. Duartmore	3
482. an Iasgaich	9	540. Magillie	3
483. Laide	9	541. na Garbh-Abhuinn Ard	3
484. Lochnaw	9	542. Scoly	3
485. Lundie (Clunie)	9	543. a' Chladaich	2
486. Moraig	9	544. an Tairbeirt Stuadhaich	2
487. Muck	9	545. Black (Tay)	2
488. Rae	9	546. Brough	2
489. Sandy	9	547. Buidhe (Tay)	2
490. Flugarth	8	548. Choire na Cloich	2
491. Fyntalloch	8	549. Dubh (Etive)	2
492. Mhic' ille Riabhaich	8	550. Dubh (Ness)	2
493. na Craige	8	551. na Creige Leithe	2
494. Skae	8	552. Rainbow	2
495. White (Tay)	8	553. Sior	2
496. a' Chaoruinn	7	554. Tilt	2
497. Asta	7	555. nan Losganan	1
498. Bosquoy	7	556. Sand	1
499. Clubbi Shuns	7	557. Uaine	0·7
500. Collaster	7	558. Dubh (Forth)	0·6
501. Cults	7	559. Setter	0·6
502. Dhomhnuill Bhig	7	560. Dhu (Portsonachan)	0·5
503. Fithie	7	561. St Margaret's	0·4
504. Moor Dam	7	562. Allt na Mult	0·1

TABLE VI

Fresh-water Lochs of Scotland (sounded by the Lake Survey) showing Summary of Physical Results

Basins.	Number of Lochs.	Number of Soundings.	Volume in Million Cubic Feet.	Area of Lochs in Square Miles.	Drainage Area.	
					Total in Square Miles.	Ratio to Area of Lochs.
Forth	13	3,825	36,543	17·02	227·66	13·38
Tay	59	6,851	151,353	39·81	1099·52	27·62
Inver, Roe, Kirkaig, Polly, Garvie	21	2,540	20,355	12·64	150·44	11·9
Morar	3	1,284	82,686	10·99	65·63	6·0
Ewe	14	2,473	44,530	14·80	185·51	12·5
Shiel, Ailort, nan Uamh .	6	1,191	28,967	8·58	99·97	11·65
Conon	16	2,188	29,850	11·65	366·33	31·5
Shin	11	1,564	14,538	12·11	239·69	19·8
Naver, Borgie, Kinloch, Hope	11	1,409	15,615	11·06	239·46	21·7
Beauly	13	841	11,227	5·76	215·26	37·4
Lochy	12	2,570	85,855	19·88	293·42	14·8
Ness	33	4,385	280,923	34·25	689·14	20·1
Brora, Helmsdale . .	11	700	2,756	6·68	202·89	30·4
Wick, Wester, Heilen, Dunnet, Thurso, Forss	9	681	1,319	4·82	168·25	34·9
Laxford, Scourie, Badcall, Duartmore . . .	10	994	6,679	3·35	59·20	17·7
Broom, Gruinard . .	11	1,141	11,312	7·10	111·50	15·7
Gairloch, Torridon, Carron	12	1,098	4,921	3·90	98·46	25·2
Alsh, Aline, Leven . .	10	570	2,067	2·51	85·25	33·9
Oban, Feochan, Seil, Melfort	13	855	1,328	1·66	34·03	20·5
Bute, Eachaig . . .	3	372	2,525	2·07	44·89	21·7
Doon, Girvan, Stinchar, Ryan, Galdenoch . .	13	1,028	1,935	3·40	75·16	22·1
Luce, Bladenoch, Cree .	15	594	427	2·12	35·43	16·7
Fleet, Dee . . .	13	954	1,951	4·02	298·89	74·4
Urr, Nith, Annan . .	14	599	652	1·79	24·77	13·7
Tweed, Monikie, Lunan, Dee, Slains . . .	16	879	5,762	4·24	121·19	28·6
Spey	13	663	2,053	2·63	350·50	133·3
Lossie, Findhorn, Nairn .	10	655	5,179	3·50	42·41	12·1
Lismore, Mull, Benbecula	11	728	5,475	3·75	35·54	9·5
North Uist . . .	40	3,751	3,026	8·66	45·29	5·2
Lewis	30	2,896	7,409	9·64	151·98	15·8
Orkney	14	932	2,321	9·98	90·36	9·1
Shetland	31	1,707	1,416	5·36	51·89	9·7
Forth (Reservoirs) . .	20	1,065	998	3·07	43·69	14·2
Etive	21	2,619	48,451	18·19	307·55	16·9
Clyde	7	2,487	93,331	29·00	314·40	10·8
Tay, Linnhe . . .	3	106	79	0·23	3·51	15·3
	562	59,195	1,015,814 = 6·9 cubic miles	340·22	6669·06	19·6

INDEX TO THE DESCRIPTIONS AND MAPS OF THE SCOTTISH FRESH-WATER LOCHS[1] SOUNDED BY THE LAKE SURVEY

[The descriptions are bound in Vol. II., the maps in Vols. III., IV., V., and VI.]

[1] The spelling of the names of the lochs is uniform with that used in the 6-inch Ordnance Survey maps.

Awe (Etive basin),	Vol. II.	Part II., p. 270;	Vol. VI.	Plates CXXII. and CXXIII.
Awe (Inver basin),	„ II.	„ I., p. 152;	„ III.	Plate XXXVI.
Bà (Mull),	„ II.	„ II., p. 175;	„ V.	„ LXVI.
Bà (Tay basin),	„ II.	„ I., p. 62;	„ III.	„ XVI.
Bad a' Chròtha,	„ II.	„ II., p. 57;	„ V.	„ XVIII.
Bad a' Ghaill,	„ II.	„ I., p. 17;	„ III.	„ XLI.
Bad an Sgalaig,	„ II.	„ II., p. 53;	„ V.	„ XVIII
Baddanloch,	„ II.	„ II., p. 10;	„ V.	„ II.
Baile a' Ghobhainn,	„ II.	„ II., p. 171;	„ V.	„ LXV.
Balgavies,	„ II.	„ II., p. 144;	„ V.	„ LI.
Beag,	„ II.	„ I., p. 394;	„ IV.	„ XCIX.
Beannach (Gruinard basin),	„ II.	„ II., p. 44;	„ V.	„ XVII.
Beannach (Inver basin),	„ II.	„ I., p. 153;	„ III.	„ XXXVI.
Beannachan,	„ II.	„ I., p. 273;	„ IV.	„ LVIII.
Beinn a' Mheadhoin,	„ II.	„ I., p. 338;	„ IV.	„ LXXIX.
Beinne Bàine, na	„ II.	„ I., p. 340;	„ IV.	„ LXXXII.
Beiste, na	„ II.	„ II., p. 46;	„ V.	„ XVII.
Beithe, na	„ II.	„ II., p. 279;	„ VI.	„ CXXXI.
Benachally,	„ II.	„ I., p. 121;	„ III.	„ XXXIII.
Benisval,	„ II.	„ II., p. 218;	„ VI.	„ LXXXIX.
Beoraid,	„ II.	„ I., p. 206;	„ III.	„ XLIV.
Bhac,	„ II.	„ I., p. 94;	„ III.	„ XXVIII.
Bhaid Daraich, a'	„ II.	„ II., p. 30;	„ V.	„ XI.
Bhaid - Luachraich, a'	„ II.	„ I., p. 228;	„ III.	„ L.
Bhaillidh, a'	„ II.	„ II., p. 68;	„ V.	„ XXVI.
Bhainne, a'	„ II.	„ I., p. 391;	„ IV.	„ XCVI.
Bharpa, a'	„ II.	„ II., p. 200;	„ VI.	„ LXXI.
Bhealaich, a' (Alsh basin),	„ II.	„ II., p. 63;	„ V.	„ XXIV.
Bhealaich, a' (Gairloch basin),	„ II.	„ II., p. 54;	„ V.	„ XIX.
Bhealaich, a' (Naver basin),	„ II.	„ I., p. 312;	„ IV.	„ LXXIII.
Bhradain,	„ II.	„ II., p. 156;	„ V.	„ LVIII.
Bhraoin, a'	„ II.	„ II., p. 38;	„ V.	„ XIV.
Bhuird, a'	„ II.	„ II., p. 186;	„ VI.	„ LXX.
Bì, na	„ II.	„ II., p. 275;	„ VI.	„ CXXVI.
Birka,	„ II.	„ II., p. 236;	„ VI.	„ XCVIII.
Black (Etive basin),	„ II.	„ II., p. 279;	„ VI.	„ CXXX.

Garbh-Clachan, nan	Vol. II.	Part II., p. 193;	Vol. VI.	Plate LXXV.
Garry (Ness basin),	,, II.	,, I., p. 389;	,, IV.	,, XCV.
Garry (Tay basin),	,, II.	,, I., p. 57;	,, III.	,, XV.
Gartmorn,	,, II.	,, II., p. 254;	,, VI.	,, CXIV.
Garve,	,, II.	,, I., p. 277;	,, IV.	,, LXI.
Gead, an	,, II.	,, I., p. 345;	,, IV.	,, LXXXII.
Geal,	,, II.	,, II., p. 266;	,, VI.	,, CXXIV.
Gealaich, na	,, II.	,, II., p. 278;	,, VI.	,, CXXIII.
Geireann, nan	,, II.	,, II., p. 190;	,, VI.	,, LXXII.
Geireann, nan (Mill),	,, II.	,, II., p. 192;	,, VI.	,, LXXIV.
Gelly,	,, II.	,, II., p. 256;	,, VI.	,, CXVI.
Ghiuragarstidh,	,, II.	,, I., p. 227;	,, III.	,, XLVII.
Ghlinne - Dor - cha, a'	,, II.	,, II., p. 193;	,, VI.	,, LXXVI.
Ghobhainn, a'	,, II.	,, II., p. 55;	,, V.	,, XIX.
Ghriama, a'	,, II.	,, I., p. 298;	,, IV.	,, LXVII.
Ghuilbinn,	,, II.	,, I., p. 368;	,, IV.	,, LXXXVII.
Giorra,	,, II.	,, I., p. 94;	,, III.	,, XXVII.
Girlsta,	,, II.	,, II., p. 234;	,, VI.	,, XCVI.
Gladhouse,	,, II.	,, II., p. 251;	,, VI.	,, CVII.
Glass,	,, II.	,, I., p. 279;	,, IV.	,, LXII.
Gleann a' Bhear-raidh,	,, II.	,, II., p. 73;	,, V.	,, XXVIII.
Gorm Loch Mòr,	,, II.	,, I., p. 300;	,, IV.	,, LXIX.
Gown,	,, II.	,, I., p. 265;	,, IV.	,, LVII.
Grass,	,, II.	,, II., p. 240;	,, VI.	,, CI.
Grennoch,	,, II.	,, II., p. 115;	,, V.	,, XLIV.
Grunavat,	,, II.	,, II., p. 214;	,, VI.	,, LXXXVI.
Gryfe,	,, II.	,, II., p. 267;	,, VI.	,, CXXXIV.
Harelaw,	,, II.	,, II., p. 253;	,, VI.	,, CXII.
Harperleas,	,, II.	,, II., p. 257;	,, VI.	,, CXVI.
Harperrig,	,, II.	,, II., p. 253;	,, VI.	,, CXI.
Harray,	,, II.	,, II., p. 225;	,, VI.	,, XC.
Harrow,	,, II.	,, II., p. 118;	,, V.	,, XLIV.
Heilen,	,, II.	,, II., p. 17;	,, V.	,, V.
Hempriggs,	,, II.	,, II., p. 15;	,, V.	,, III.
Heouravay,	,, II.	,, II., p. 178;	,, VI.	,, LXVIII.
Hermidale,	,, II.	,, II., p. 179;	,, VI.	,, LXVIII.
Hightae Mill,	,, II.	,, II., p. 132;	,, V.	,, XLVII.
Hoglinns,	,, II.	,, II., p. 229;	,, VI.	,, XCIV.
Hoil,	,, II.	,, I., p. 114;	,, III.	,, XXXI.
Holl,	,, II.	,, II., p. 257;	,, VI.	,, CXVII.
Hope,	,, II.	,, I., p. 324;	,, IV.	,, LXXVII.
Hosta	,, II.	,, II., p. 192;	,, VI.	,, LXXIII.

Leitreach, na	Vol.	II.	Part	II., p. 63;	Vol.	V.	Plate	XXIII.
Leodsay,	„	II.	„	II., p. 193;	„	VI.	„	LXXV.
Leòid, an	„	II.	„	II., p. 277;	„	VI.	„	CXXIII.
Leum a' Chla-mhain,	„	II.	„	II., p. 6;	„	V.	„	II.
Leven,	„	II.	„	I., p. 18;	„	III.	„	XI.
Liath,	„	II.	„	I., p. 398;	„	IV.	„	CI.
Lindores,	„	II.	„	II., p. 260;	„	VI.	„	CXIX.
Linlithgow,	„	II.	„	II., p. 254;	„	VI.	„	CXIII.
Lintrathen,	„	II.	„	I., p. 123;	„	III.	„	XXXIII.
Littlester,	„	II.	„	II., p. 246;	„	VI.	„	CV.
Loch,	„	II.	„	I., p. 97;	„	III.	„	XXVIII.
Lochaber,	„	II.	„	II., p. 127;	„	VI.	„	XLVI.
Lochenbreck,	„	II.	„	II., p. 116;	„	V.	„	XLIV.
Lochindorb,	„	II.	„	II., p. 164;	„	V.	„	LXIII.
Lochinvar,	„	II.	„	II., p. 118;	„	V.	„	XLIV.
Lochnaw,	„	II.	„	II., p. 101;	„	V.	„	XXXIX.
Lochrutton,	„	II.	„	II., p. 127;	„	V.	„	XLVI.
Lochy,	„	II.	„	I., p. 356;	„	IV.	„	LXXXIII.
Lomond,	„	II.	„	II., p. 262;	„	VI.	„	CXXIV. and CXXV.
Long,	„	II.	„	I., p. 111;	„	III.	„	XXX.
Losgainn Mòr, an	„	II.	„	II., p. 81;	„	V.	„	XXXI.
Losganan, nan	„	II.	„	I., p. 407;	„	IV.	„	CIII.
Lowes (Tay basin),	„	II.	„	I., p. 101;	„	III.	„	XXIX.
Lowes (Tweed basin),	„	II.	„	II., p. 136;	„	V.	„	XLIX.
Loyne,	„	II.	„	I., p. 396;	„	IV.	„	C.
Lubnaig,	„	II.	„	I., p. 11;	„	III.	„	VI.
Luichart,	„	II.	„	I., p. 271;	„	IV.	„	LX.
Lundie (by Clunie),	„	II.	„	I., p. 396;	„	IV.	„	XCIX.
Lundie (by Garry),	„	II.	„	I., p. 391;	„	IV.	„	XCVI.
Lungard,	„	II.	„	I., p. 341;	„	IV.	„	LXXXII.
Lùnn dà-Bhrà,	„	II.	„	I., p. 372;	„	IV.	„	XC.
Lure,	„	II.	„	II., p. 96;	„	V.	„	XXXVII.
Lurgain,	„	II.	„	I., p. 172;	„	III.	„	XL.
Lyon,	„	II.	„	I., p. 72;	„	III.	„	XXI.
Maberry,	„	II.	„	II., p. 106;	„	V.	„	XL.
Magillie,	„	II.	„	II., p. 103;	„	V.	„	XXXIX.
Màma,	„	II.	„	I., p. 256;	„	IV.	„	LVI.
Maol a' Choire,	„	II.	„	I., p. 152;	„	III.	„	XXXVI.
Maree,	„	II.	„	I., p. 211;	„	III.	„	XLVI. and XLVII.
Martnaham,	„	II.	„	II., p. 94;	„	V.	„	XXXVI.
Meide, na	„	II.	„	I., p. 309;	„	IV.	„	LXXI.

Tarruin an Eithir,	Vol.	II.	Part	II., p. 200;	Vol.	VI.	Plate	LXX.
Tay,	„	II.	„	I., p. 80;	„	III.	„	XXIV. and XXV.
Teàrnait,	„	II.	„	II., p. 67;	„	V.	„	XXV.
Thom,	„	II.	„	II., p. 267;	„	VI.	„	CXXXIV.
Threipmuir,	„	II.	„	II., p. 253;	„	VI.	„	CXII.
Tilt,	„	II.	„	I., p. 96;	„	III.	„	XXVIII.
Tingwall,	„	II.	„	II., p. 243;	„	VI.	„	CIII.
Tollie,	„	II.	„	I., p. 225;	„	III.	„	XLVII.
Tomain, an	„	II.	„	II., p. 193;	„	VI.	„	LXXVI.
Tormasad,	„	II.	„	II., p. 199;	„	VI.	„	LXXI.
Tralaig,	„	II.	„	II., p. 78;	„	V.	„	XXXI.
Trealaval,	„	II.	„	II., p. 208;	„	VI.	„	LXXX.
Treig,	„	II.	„	I., p. 369;	„	IV.	„	LXXXVIII.
Trool,	„	II.	„	II., p. 110;	„	V.	„	XLII.
Truid air Sgi-thiche,	„	II.	„	II., p. 8;	„	V.	„	II.
Tuirc, an	„	II.	„	I., p. 157;	„	III.	„	XXXVII.
Tulla,	„	II.	„	II., p. 274;	„	VI.	„	CXXVIII.
Tummel,	„	II.	„	I., p. 78;	„	III.	„	XXIII.
Turret,	„	II.	„	I., p. 117;	„	III.	„	XXXII.
Tùtach,	„	II.	„	II., p. 165;	„	V.	„	LXII.
Uaine,	„	II.	„	I., p. 118;	„	III.	„	XXXII.
Uanagan,	„	II.	„	I., p. 394;	„	IV.	„	XCVIII.
Urigill,	„	II.	„	I., p. 160;	„	III.	„	XXXVI.
Urr,	„	II.	„	II., p. 124;	„	V.	„	XLIII.
Urrahag,	„	II.	„	II., p. 212;	„	VI.	„	LXXXIII.
Ussie,	„	II.	„	I., p. 278;	„	IV.	„	LXI.
Vaara,	„	II.	„	II., p. 238;	„	VI.	„	C.
Valtos,	„	II.	„	II., p. 208;	„	VI.	„	LXXX.
Vatandip,	„	II.	„	II., p. 211;	„	VI.	„	LXXXI.
Veiragvat,	„	II.	„	II., p. 191;	„	VI.	„	LXXII.
Vennachar,	„	II.	„	I., p. 6;	„	III.	„	V.
Veyatie,	„	II.	„	I., p. 163;	„	III.	„	XXXVIII.
Voil,	„	II.	„	I., p. 9;	„	III.	„	VII.
Vullan, a'	„	II.	„	I., p. 399;	„	IV.	„	CI.
Watten,	„	II.	„	II., p. 15;	„	V.	„	III.
Wester,	„	II.	„	II., p. 17;	„	V.	„	IV.
Whinyeon,	„	II.	„	II., p. 120;	„	V.	„	XLIV.
White (Ryan basin),	„	II.	„	II., p. 100;	„	V.	„	XXXVIII.
White (Tay basin),	„	II.	„	I., p. 108;	„	III.	„	XXX.
White of Myr-ton,	„	II.	„	II., p. 105;	„	V.	„	XXXIX.
Whitefield,	„	II.	„	II., p. 104;	„	V.	„	XXXIX.
Woodhall,	„	II.	„	II., p. 116;	„	V.	„	XLIV

THE FRESH-WATER LOCHS OF SCOTLAND

INTRODUCTION

By Sir JOHN MURRAY, K.C.B., F.R.S., D.Sc., etc.

I.—Origin and History of the Lake Survey Work

During the *Challenger* and some subsequent deep-sea expeditions I spent many years in the exploration of the physical and biological conditions of the great ocean basins. While preparing the scientific results of these expeditions for publication, it seemed to me that, for the purpose of comparison, a detailed examination of the fjord-like sea-lochs of the coasts of Scotland might yield very valuable information. In order to undertake an investigation of this kind it was necessary to have a small steam yacht fitted with the necessary arrangements for taking deep-sea temperatures, for dredging and trawling, and other like operations. With the assistance of Mr A. P. Henderson, the late Mr John Henderson (both of the firm of Messrs D. & W. Henderson, of Partick), and financial assistance from my life-long friend Mr Laurence Pullar, of The Lea, Bridge of Allan, I was able to build a small thirty-ton steam yacht, fully equipped for oceanographical investigations near shore. This yacht was called the *Medusa*, and during the years 1884 to 1891 she was almost continually employed in exploring the shallow waters and deep land-locked sea-lochs of the coasts of Scotland. During the same period a biological laboratory was carried on at Granton, near Edinburgh, and another similar laboratory in a large canal-barge, called *The Ark*, at Millport, Cumbrae, on the west coast of Scotland. This latter laboratory ultimately developed into the Robertson Museum and the laboratory of the Marine Biological Association of the West of Scotland, at Millport. Many valuable results were obtained by these investigations, in which Dr H. R. Mill, Mr J. T. Cunningham, Mr H. N. Dickson, the late Mr John Rattray, and many other physicists, chemists, and biologists took part.[1]

While carrying on these researches in the sea-lochs of Scotland the *Medusa* made several excursions into the fresh-water lochs in the line of the Caledonian Canal—Loch Lochy, Loch Oich, and Loch Ness. Nothing could be more striking than the difference in the physical and biological conditions presented by the salt- and the fresh-water lochs. In salt water the maximum density point is below the freezing point, so that the colder water at the surface always tends to sink to the bottom. In fresh water the maximum density point is 39°·2 Fahr., so that water at this temperature tends to sink to the bottom, while water above or below 39°·2 Fahr. remains at the surface. This physical fact governs the very different distribution of temperature and

[1] Cunningham, J. T., "On the Relations of the Yolk to the Gastrula in Teleosteans, and in other Vertebrate Types," *Quart. Journ. Micr. Sci.*, vol. xxvi., N.S., p. 1, 1885.

Henderson, J. R., "The Decapod and Schizopod Crustacea of the Firth of Clyde," *Trans. Nat. Hist. Soc. Glasgow*, 1886.

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Cunningham, J. T., and R. Vallentin, "The Luminous Organs of *Nyctiphanes norvegica*," *Proc. Roy. Soc. Edin.*, vol. xiv. pp. 351–356, 1887; also *Quart. Journ. Micr. Sci.*, vol. xxviii. pp. 319–343, 1888.

Rattray, John, "Revision of the Genus *Aulacodiscus*; Revision of the Genus *Aulisca*," *Journ. Roy. Micr. Soc.*, 1888.

Hoyle, W. E., "On the Deep-Water Fauna of the Clyde Sea-Area (with map)," *Journ. Linn. Soc. Lond.*, Zoology, vol. xx. pp. 442–472, 1889.

Murray, John, "On the Temperature of the Salt- and Fresh-Water Lochs of the West of Scotland, at different Depths and Seasons, during the years 1887 and 1888," *Proc. Roy. Soc. Edin.*, vol. xviii. pp. 139–228, 1891.

Murray, John, and R. Irvine, "On Silica and the Siliceous Remains of Organisms in Modern Seas," *Proc. Roy. Soc. Edin.*, vol. xviii. pp. 229–250, 1891.

Mill, H. R., "The Clyde Sea Area," *Trans. Roy. Soc. Edin.*, vol. xxxvi. pp. 641 and 664, 1892.

Murray, John, and R. Irvine, "On the Chemical Changes which take place in the Composition of the Sea-Water associated with Blue Muds on the Floor of the Ocean," *Trans. Roy. Soc. Edin.*, vol. xxxvii. pp. 481–507, 1893.

Murray, John, and R. Irvine, "On the Manganese Oxides and Manganese Nodules in Marine Deposits," *Trans. Roy. Soc. Edin.*, vol. xxxvii. pp. 721–742, 1894.

And numerous other papers.

circulation of the water in a salt- and a fresh-water lake, under the influence of wind and other physical agents.

In a salt-water loch, again, there is a great profusion of life in depths of 500 and 600 feet, and many organisms from these depths, as well as large numbers of other organisms taken at the surface, exhibit most remarkable displays of phosphorescent light. In a fresh-water loch, from similar depths, and under the same climatic conditions, the dredge or trawl brings up not more than half a dozen dwarfed species, and the phenomenon of phosphorescent light has never been observed in fresh-water organisms.[1] The organic matter associated with the muds and other deposits from a salt-water loch undergoes rapid decomposition, and soon renders the water foul and unsuited for living creatures. In the deposits from a fresh-water loch, although chemical analysis shows abundance of organic matter, the water does not become foul so rapidly, and organisms may live in water associated with the deposits for days and weeks. These phenomena are apparently connected with the activity of two species of bacteria in decomposing the sulphates in solution—*Microspira desulphuricans* in fresh water, and *Microspira estuarii* in salt water.

The above and many similar observations led me to conclude that a systematic survey of the fresh-water lochs of Scotland would in all likelihood result in many new additions to natural knowledge, and would be especially important for comparison with results in other departments of scientific endeavour. I found that many geologists were most anxious for a bathymetrical survey of these lochs, in connection with the discussion as to the origin of lake-basins. Fishermen, and engineers who had to do with the water supply of towns and the development of water power, were also interested in this subject. On my initiation this matter was brought before the Councils of the Royal Society of London and of the Royal Society of Edinburgh. After careful consideration both Councils during the years 1883 and 1884 made very strong representations to the Government, urging that a bathymetrical survey of the Scottish fresh-water lochs should be at once undertaken in the interests of scientific progress. There was no practical outcome from these representations. The reply of the Treasury, dated 17th September 1883, and signed by Mr Leonard Courtney (now Lord Courtney), was to the effect that a survey of the kind indicated did not come within the functions of the Admiralty, which only undertook work in the interests of navigation, nor of the Survey Department of the Office of Works (late Ordnance Survey), which limited its operations to the dry land, and that, however interesting from a scientific point of view, their Lordships were unable

[1] See notes by T. Jamieson in the *Aberdeen Free Press*, 19th November 1908, and in *Nature*, vol. lxxix. p. 309, 1909, as to phosphorescent displays in Loch Builg.

to sanction the proposed surveys. The correspondence on this subject will be found appended to this Introduction (Appendix I.).

Bathymetrical charts of Loch Lomond and Loch Awe were published by the Hydrographic Department of the Admiralty about the year 1860, based on surveys undertaken by naval officers. Some of the general charts of the Scottish coasts published by the Admiralty show a few soundings down the centre of the lochs of the Caledonian Canal, but the charts of Loch Lomond and Loch Awe were the only systematic surveys of Scottish fresh-water lochs that existed at the time the above-mentioned representations were laid before the Government. It is true that previous to this date many Scottish proprietors and others had made most praiseworthy endeavours to ascertain the depths of many of the lochs, but these were generally not laid down on charts or made public. In the year 1887 Mr J. Y. Buchanan recorded a depth of 175 fathoms in Loch Morar; and in 1888 I sounded all along this loch, and recorded a depth of 180 fathoms at one spot. At about the same time both Mr Buchanan and I took very many soundings in Loch Lochy and Loch Ness. I had also taken many soundings in Loch Katrine and other Scottish lochs before attempting any systematic survey. In the year 1888 the late Mr J. S. Grant Wilson, of the Geological Survey, published in the *Scottish Geographical Magazine* an account of Lochs Tay, Earn, Rannoch, and Tummel, with special reference to the glaciation of the district, and he gave small contoured maps of these lochs, in which the position of some of the deeper soundings was laid down. This represents the state of knowledge of the depths of the Scottish fresh-water lochs at the time when I commenced, with the assistance of my young friend the late Mr Fred. P. Pullar, to attack the problem in a systematic way about 1897. We were led to take up this self-imposed task because, as above stated, there was no hope of the work being undertaken by any Government department.

A start was made with the lochs of the Forth basin, but a good deal of preliminary work had to be undertaken before quite satisfactory methods were arrived at for carrying on the work of the survey. Indeed, some of the lochs were surveyed two and even three times with different sounding-machines, and by different methods of determining the position of the soundings. When these initial difficulties were overcome the work proceeded as rapidly as the time at our disposal permitted, being at that time regarded as a holiday task. The first paper—on the lochs of the Trossachs and Callander district—was published in April 1900; and a second paper, dealing with the other lochs of the Forth basin and two lochs of the Tay basin, appeared in March 1901.

It so happened that I had to visit the East during the winter of

1900–1901, going out by way of Canada and the Pacific, and returning by India and the Suez Canal. There was at one time a suggestion that my young friend Mr Fred. Pullar should accompany me on this trip, but this was not possible for a variety of reasons. Our last day's sounding to complete the work for the second of the above-mentioned papers was on Loch Leven, on the 1st September 1900, and during lunch-time we amused ourselves by taking each other's photographs (see figs. 1 and 2) with the kodak I was to take with me on the trip round the world. When we parted it was arranged that Mr Pullar should see the final paper on the lochs of

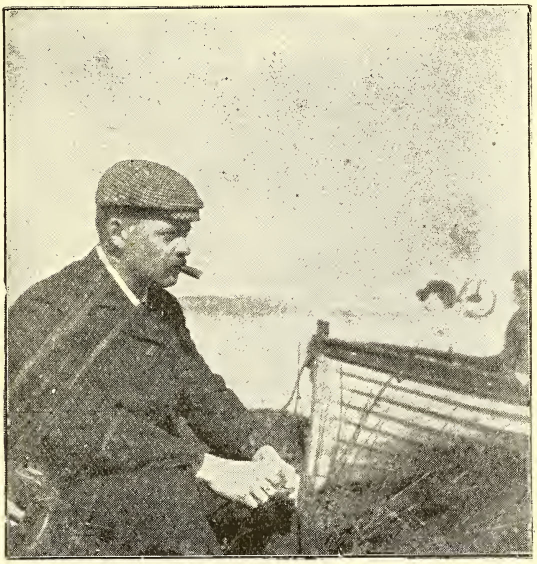


Fig. 1.—The late Fred. P. Pullar, F.R.S.E.

(From a photograph by Sir John Murray, taken on the shores of Loch Leven, 1st September 1900. Lunch-time on his last sounding expedition.)

the Forth basin through the press, and further that on my return we should proceed with the survey of all the Scottish fresh-water lochs at our mutual expense.

I returned to London from the East on the evening of the 16th February 1901, and on entering my hotel was handed a telegram announcing that my vigorous and talented young friend and collaborator had lost his life on the previous day while gallantly attempting to rescue a number of people who, through an ice accident, had been immersed in Airthrey Loch, within a mile of his own home. Thus ended what promised to be a brilliant scientific career. His tragic death produced a profound sensation throughout the community where he was personally known, and among scientific and other friends in all parts of the world. Many appreciative notices of his death were published and local memorials established to his memory (see Appendix II.).

This untoward event brought the lake survey work to a standstill, and it was my intention to abandon it altogether. Mr Laurence Pullar, the father of my young friend, wished, however, to see the work in which his son had taken so deep an interest brought to a satisfactory conclusion. He expressed his willingness to take his son's place so far as possible, and, at all events, to set apart a sum of money to pay for such assistance as I might desire to carry on the work and to publish the results of the investigations. Mr Laurence Pullar

Fig. 2.—Sir John Murray, K.C.B.

(From a photograph taken by the late F. P. Pullar, F.R.G.S., during lunch-time on their last sounding expedition together. Loch Leven, 1st September 1900.)

desired to be assured on two points: *first*, that there was no likelihood of the Government undertaking such a survey in the near future; and *second*, that this survey was considered by competent scientific authorities to be desirable and important from a national point of view. In these circumstances the question of the renewal of the survey work was brought before the Councils of the Royal Societies of London and Edinburgh, as well as before the British Association at its meeting in Glasgow in 1901. All these organisations passed resolutions stating that they learned with great satisfaction that arrangements were under consideration for the completion of the survey commenced by Sir John Murray and the late Mr F. P. Pullar, and confirmed the opinion as to the great scientific importance of the investigation. These resolutions are given in Appendix III. to this Introduction.

Mr Laurence Pullar at once handed over to a small trust a sum of £10,000 in Consols to provide the means for carrying on the work on the lines that have been indicated. A copy of the trust-deed will be found in Appendix IV. to this Introduction.

Although His Majesty's Government could not see its way to undertake a bathymetrical survey of the Scottish fresh-water lochs, still several public departments have taken a deep interest in the work and have given important assistance. A letter was received from Colonel (now Sir) Duncan A. Johnston, R.E., Director-General of the

Fig. 3.—Memorial Bronze to F. P. Pullar, by Sir G. A. Frampton, R.A., erected in Logie Churchyard, Bridge of Allan.

In the central group the hero is shown supported by angel figures, whose wings form a canopy and throw shadows symbolical of the mystery beyond ; in front walk heralds carrying a laurel wreath, and behind others playing musical instruments. The legend is, "So He bringeth them unto their desired haven."

Ordnance Survey, stating that the Board of Agriculture had sanctioned the issue to the staff of the survey of two copies of the 6-inch and one copy of the 1-inch maps of the districts in which lakes were situated, one copy of the former to be returned to the department with the depths of the lakes laid down on it, with a view to the lake-contours being shown on the Ordnance Survey maps. T. Digby Piggott, Esq., C.B., Controller of His Majesty's Stationery Office, wrote to the effect that no objection would be raised by his department, on the ground of copyright, to the reproduction of Ordnance Survey maps, and publication if desired, in connection with the Lake Survey, on the understanding that the source from which the reproductions were taken was quoted, and due acknowledgment made of the fact that the consent of the Controller had been obtained. The tracings of all these 6-inch survey maps, with the soundings laid down, were sent to the Ordnance Survey Office as the work proceeded, and are now in the possession of this Government department for safe-keeping and reference (see App. V.). The bathymetrical maps which are published in this work are all reduced to the scale of three inches to the mile.

The late Admiral Sir W. J. L. Wharton, K.C.B., F.R.S., Hydrographer to the Admiralty, also promised the advice and assistance of his department. Through Mr J. J. H. Teall, F.R.S., Director-General of the Geological Survey, and Dr John Horne, F.R.S., Director of the Geological Survey of Scotland, I was informed that the Board of Education had sanctioned the issue to the Lake Survey staff of a complete set of the Geological Survey maps of Scotland, and, in addition, had sanctioned the supply of information which might be asked for by the staff of the Lake Survey during the course of their investigations. This latter privilege has been very largely taken advantage of, and Dr Horne and the other members of the Geological Survey in Scotland have rendered continuous advice and assistance, and directions were given for the preparation of maps and notes concerning the surface geology of some of the areas in which the lakes are situated. These maps and notes form a valuable part of the present publications.

All plans for carrying on the work having matured during the winter of 1901–1902, a staff was appointed,[1] and a start was made

[1] Mr T. N. Johnston, M.B., C.M. (Edin.), F.R.S.E., was appointed first assistant and zoologist; the late Mr James Parsons, B.Sc. (Lond.), chemist; Mr James Murray, assistant zoologist; Mr T. R. H. Garrett, B.A., Jesus College, Cambridge, geologist; Mr John Hewitt, B.A., Jesus College, Cambridge, zoologist; Mr James Chumley, secretary, assisted by Mr Robert Dykes, in charge of office work. Mr R. M. Clark, B.Sc., Aberdeen, also devoted a large part of the summer to field-work in connection with the survey; and assistance was also given for short periods by Dr J. Sutherland Black, M.A., F.R.S.E., Sir John Jackson, LL.D., Mr D. C. M'Intosh, M.A., Mr James Walker, C.E., and Mr D. J. Scourfield.

During the winter of 1902–3 Mr Parsons was appointed to a post on the Mineralogical Survey of Ceylon (he unfortunately lost his life in the jungle in March 1909), and Mr Garrett was appointed geologist to an East Borneo company, their places on the staff being taken by Mr R. B. Young, M.A., and Mr R. C. Marshall, M.A. Mr E. M. Wedderburn, M.A., Mr E. R. Watson, B.A., B.Sc., Jesus College, Cambridge, and Mr Scourfield and others rendered assistance. In June 1903 Mr Young was appointed to a post in the South African College, and his place on the staff was taken by Mr J. H. M. Wedderburn, M.A., F.R.S.E. In January 1904 Mr E. R. Watson left to take up a professorship in Calcutta, and in August 1904 Mr J. Hewitt and Mr R. C. Marshall left, the former to take up a teaching appointment, and the latter to continue his studies. In June 1904 Mr G. West was appointed as botanist, resigning in April 1906 to take up his duties as assistant to the Professor of early in the spring of 1902 in the lochs situated in the more northerly part of the Tay basin, the survey being gradually extended to the lochs northwards of this region, and subsequently to all the river-basins on the mainland of Scotland, as well as the western and northern islands.

Up to the time of Mr F. P. Pullar's death, 15 lochs had been surveyed; during 1902, 154 lochs were surveyed; during 1903, 250 lochs were surveyed; during 1904, 84 lochs were surveyed; during 1905, 33 lochs were surveyed; during 1906, 26 lochs were surveyed; making a total of 562 lochs in all. These include all the important lochs in Scotland, and bathymetrical maps of each one are given in the accompanying volumes. The only Scottish lochs left unsounded were those which had no boats on them, or to which boats could not readily be transported.

The actual sounding work thus extended from the beginning of 1902 to the end of 1906, but biological observations in the field were carried on by Mr James Murray during the first half of 1907, until he left to take part in Lieutenant Shackleton's Antarctic expedition; and Mr E. M. Wedderburn also carried on physical observations in the field during the years 1908 and 1909. Nearly fifty persons have taken part in the work of the Lake Survey for longer or shorter periods, as well as numerous boatmen and assistants employed temporarily for a few days in different parts of the country. In all, over 60,000 soundings were recorded in the Scottish lochs.

Mr Laurence Pullar and I are very much indebted to all the members of the Lake Survey staff for their enthusiasm and devotion. Where all have worked so well, it is perhaps invidious to mention anyone specially; still, it may be but right to say that Mr T. N. Johnston, M.B., C.M., took a very large part in the general superintendence of the field work from 1902 to 1907, and that Mr James

Botany in Dundee University College. In 1905 Mr Ch. Linder, D.Sc., and Mr L. W. Collet, D.Sc., took part in the work for short periods, and Mr C. H. Martin, B.A., devoted some months in the summers of 1905 and 1906 to the study of worms in various lochs. In the summer of 1905 Professor Chrystal undertook a systematic investigation into the seiches of Loch Earn and some of the neighbouring lochs, and in this work he was assisted by Mr J. D. Fulton, B.Sc., Mr William Watson, M.A., and Mr Peter White, M.A. Several foreign limnologists have visited the Scottish lochs, and have made observations on their fauna and flora, etc., for comparison with continental lakes, as for instance, Dr C. Wesenberg-Lund of Lyngby, Denmark; Dr H. Bachmann of Zürich, Switzerland; and Dr W. Halbfass of Neuhaldensleben, Germany. Father Odo Blundell and Father Cyril von Dieckhoff, of St Benedict's Monastery, Fort Augustus, rendered valuable assistance during and subsequent to the survey of Loch Ness. Recently Miss Stewart and Miss Drummond have been engaged in office work connected with the preparation of this report, and Dr W. A. Caspari has made an examination of the deposits from the various lochs from a chemical point of view.

Chumley had charge, during the whole period covered by the survey, of the accounts and payments of the staff, and of the instruments, charts, and note-books which were despatched to or returned from the workers in the field. Mr Chumley has also taken a large part in the preparation of the manuscript of this Report and the correction of the proof-sheets. This is especially true with regard to the special descriptions of the river basins and lochs. He has also superintended and been responsible for the planimeter measurements and calculations by the other assistants. Mr Chumley's previous experience as my assistant in the preparation of the *Challenger* Reports in a very special manner qualified him for these duties. A list of all those who have taken part in the work of the survey is given in Appendix VI.

We desire also to acknowledge the courtesy and assistance rendered by Scottish proprietors in the loan of boats, the help of keepers and other employees, and in many other directions. It is impossible to mention these by name in this place, but without their co-operation the work could not have proceeded. In some few cases the surveyors were looked on with a little suspicion, but the great majority of proprietors took a lively and intelligent interest in the survey. It was rather amusing at times to observe the result of the soundings on the inhabitants of districts in which the lochs are situated. As a rule, lochs, or some parts of a loch, are regarded as very deep or without bottom. When a loch with this reputation was found to be relatively shallow, the result would be questioned, and a feeling of affront or injury prevailed among the inhabitants of the district.

The whole undertaking has occupied a large part of my time and thought during the past six or seven years, and has entailed a good deal of hard work both in the field and in the study. On the other hand, it has been a great pleasure to have been closely associated in this work with my old friend Mr Laurence Pullar, with the members of the staff, and all those who have voluntarily offered assistance for longer or shorter periods in one direction or another.

II.—Methods and Instruments

Sounding-Machines.—The first attempts at sounding the Scottish lochs were made with the ordinary hempen hand-line. It is possible to sound small and shallow lochs in this way, but to have used this method in the deeper and larger lochs would have taken a very long time; besides, the slow rate of hauling in this line would have increased very greatly the difficulty of determining the position of the soundings owing to the drifting of the boat. In order to accelerate the work it was necessary to procure a portable wire sounding-machine that could be used in small rowing-boats. The only instrument of this kind available in 1895 was one constructed by Dr Ule, and exhibited at the Sixth International Geographical Congress in London (1895). This apparatus was purchased by Mr Fred. P. Pullar, and with it numerous soundings were taken in Loch Morar, Lochs Frisa, Ba, and Uisg in Mull, and also in Lochs Katrine,

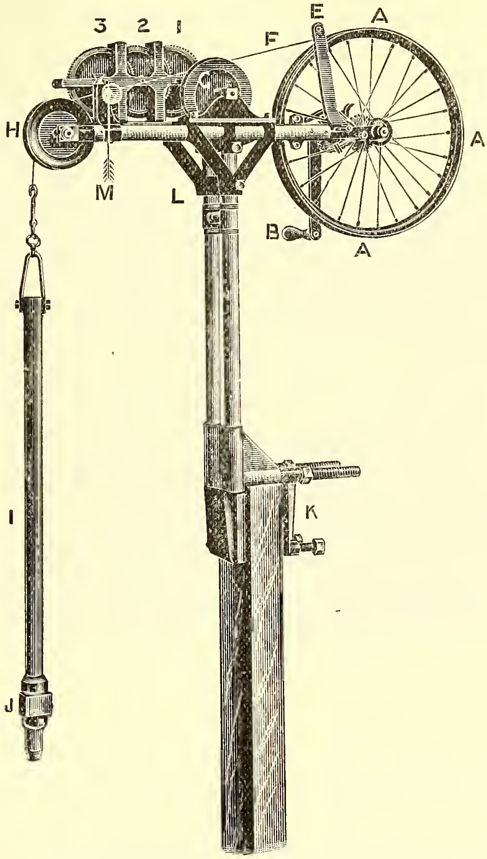


Fig. 4.—F. P. Pullar Sounding-Machine.

Lubnaig, Voil, and Doine. It proved most unsatisfactory, for after a few months' use the registration of the depths was found to be quite untrustworthy, and it was consequently discarded. Subsequently Mr F. P. Pullar designed the sounding-machine represented in fig. 4, and now known as the F. P. Pullar sounding-machine.[1] This in the

[1] The sounding-machine (see fig. 4) is constructed of steel cycle-tubes, which are held in position by means of gun-metal brackets, and is divided into two sections in order to pack into as little space as possible for transport. The first section consists of a bracket, carrying two upright tubes, with an adjustable clamp (K),

hands of the Lake Survey staff has worked admirably and accurately. Fig. 5 shows the method of using the machine from a small boat; it can be used in a similar manner from a steam launch or yacht. The Pullar sounding-machine was used in all the larger lochs, but for small hill-lochs, difficult of access, it was found advisable to construct several small machines (see fig. 6), which could be carried in the hand or on a bicycle, and be easily attached to a rowing-boat. A hand-line was used in these machines, marked in feet in the usual way.

Fig. 5.—Method of Sounding.
(From a photograph by Lady Murray.)

Although the soundings took a much longer time, still this instrument proved most satisfactory for hill-lochs in remote positions.

by means of which the machine is fixed to the gunwale of the boat. Over the ends of the two upright tubes, at the disconnecting joint (L), is slipped the second section of the machine, consisting of two horizontal tubes, to which the drum with the sounding wire, measuring pulley, indicating dials, grease-box, etc., are all fixed. The drum (A), which carries the wire, is a small suspension wheel, with a U-shaped rim, tangent spokes, and gun-metal hub. The hub has cone bearings, which can be screwed up, so that any wear may be allowed for. The rim of the drum is capable of holding over 1000 feet of three-strand galvanised steel wire (F). On the hub of the drum is fixed a bronze pinion-wheel, in gear with another pinion-wheel fitted with a crank handle (B), by means of which the wire on the rim of the drum may be wound in, and on the other side of the hub is an adjustable band-brake (E) intended to regulate the speed of the wire when running out. There is also a stop for the purpose of preventing the weight from running out when the machine is not in use. The wire, after leaving the drum, takes a

A small Lucas sounding-machine was presented to the Lake Survey by the Telegraph Construction and Maintenance Company, and, although rather heavy for constant transport, was used with great

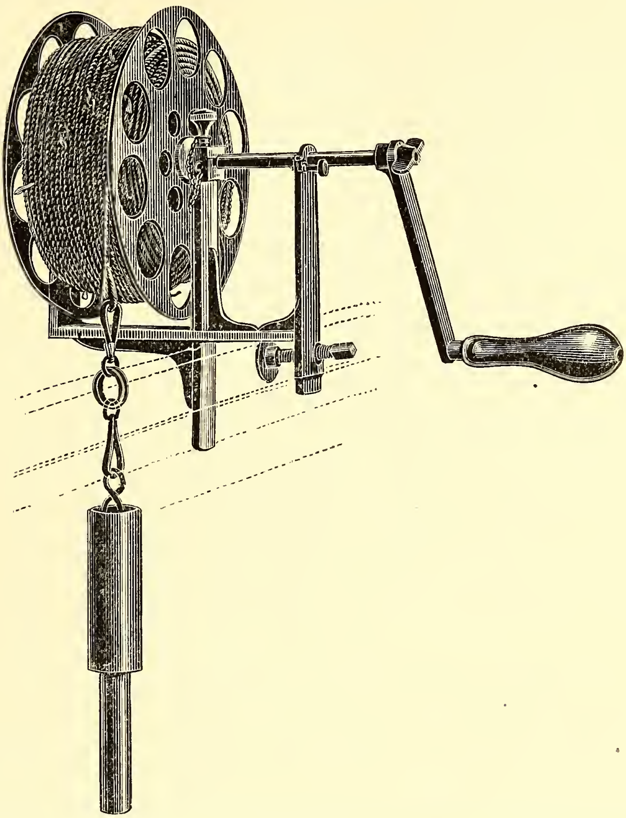


FIG. 6.—Small Sounding-Machine for use in small and shallow lochs.

success in the larger lochs for sounding and taking temperatures in deep water. This machine and one of the Pullar sounding-machines

complete turn round a measuring pulley (G), then through a grease-box (M), and over a guide pulley (H) to the weight (I), which takes the form of a sounding-tube constructed to procure a sample of the deposit, with flap-valve (J) at the foot, the wire being attached to the weight by means of a splice and clip-hook. The measuring pulley has a circumference of nearly one foot (measured through the centre of the wire it is exactly one foot), so that for every foot of wire which runs out the measuring pulley makes one revolution. The motion of the measuring pulley is transmitted to a series of indicating dials (1, 2, and 3), one recording feet, another tens, and a third hundreds of feet. When the weight strikes the bottom the motion ceases, and the depth may be read off the indicating dials. The dials fitted to the present machine read only to a depth of 999 feet 6 inches, but by the addition of an extra dial greater depths could be sounded.

were sent in 1905 to Lieutenant Robert Peary for use in his Arctic expeditions across the polar ice.

Methods of Determining Positions of Soundings.—At the outset much time was spent in trials as to the best method of determining the positions of the soundings:—1, by the sextant from the boat; 2, by signals from the boat, when a sounding was taken, to observers on the shore; and 3, by running lines with two poles placed one behind the other on shore. All these methods took a great deal of time, and the fixing of the position was complicated by the drifting of the boat with both wind and water currents. After repeated trials and a comparison of results, it was found that the most accurate method was to take the soundings as quickly as possible while rowing across the lochs from one point to another. Before making a section across a loch, the boatman was trained for some time to ascertain the distance covered in ten, fifteen, twenty, and fifty strokes with the oars. It was usual to row from a definite point on one side of the loch to a definite point on the other side, keeping objects one behind another in line. The distance between these two points was ascertained from the 6-inch Ordnance Survey maps, which were throughout used for plotting the position of the soundings. The soundings were taken, say, every thirty strokes of the oars, and the total number of soundings was placed equally along the line, thus distributing any errors. This method was found to be extremely accurate for long, narrow lochs; it is less correct in wide lakes without islands. Frequently the position of soundings near shore was ascertained by measurement with tape-lines or cords, several hundred feet in length, stretched from the shore. In addition to cross lines, soundings were usually taken in several positions between the lines. When any special features were indicated by the soundings, several series were taken radially from a fixed point.[1]

The level of the surfaces of the lochs at the time of sounding was obtained by measurement with a surveyor's level and staff[2] to the bench-marks along the shores of the lochs. In the case of lochs at a high altitude it was frequently not possible to refer the surface to a bench-mark by levelling, owing to the great distance, and the spot levels were unsatisfactory. However, special Lake Survey marks were placed along the shore, showing the height of the surface at the time

[1] For the purpose of maintaining position in running lines of soundings across a loch, mirrors of alignment of different forms were used—one supplied by Chabaud of Paris from the designs of Professor Thoulet; by means of these mirrors an object on shore *behind* the surveyor is kept in line with another object on shore *in front* of the surveyor.

[2] A surveyor's dumpy level and figured staff, as well as small Abney levels, were used for this purpose.

of the survey. Only in exceptional cases was it necessary to apply corrections to the soundings for a rise or fall of the surface during the sounding operations.

Preparation of the Maps.—When the survey of a loch had been completed, the 6-inch Ordnance Survey map, with soundings laid down in position by the surveyors, and the sounding-book relating thereto, together with any special notes, were forwarded to the office in Edinburgh, where clean tracings on cloth were plotted, carefully compared with the sounding-book; and contour-lines of depth drawn in at equal intervals. The areas within the consecutive contour-lines were then measured with the planimeter, and the volume of water contained in the loch, and the mean depth, calculated. The area draining into the loch was measured with the planimeter on the 1-inch Ordnance Survey map, and all particulars as to elevation, number of soundings taken, length, breadth, depth, area, and drainage area were entered in a large book ruled for the purpose. The tracings were then handed to Mr Bartholomew, who prepared copies on thin paper, with the printed names, etc., inserted in position. These were carefully revised in the office, and then reduced by photography to half-size (*i.e.* to the scale of 3 inches to the mile) and transferred to stone, all the maps in these volumes being on that scale. After the publication of the printed maps the tracings on cloth were forwarded to the office of the Ordnance Survey for preservation and for future reference.

Temperature Observations.—These were made in most of the lochs by means of Negretti & Zambra's deep-sea thermometers, which were immersed to different depths by the sounding-line and reversed by a messenger sent down the line. Different forms of frames and mechanisms for reversing the thermometers were experimented with, and it was found that the Scottish frame with side lever, originally designed in connection with the work of the Granton Marine Station, was the most satisfactory (figs. 7 and 8).[1] Several

[1] In fig. 7, F is the frame attached to sounding-line by the clamp V and the short spiral C.

T, thermometer turning in frame on pivots *p p*.

P, iron pin passing through holes at *h h*, and projecting into groove at top of thermometer case at G.

L, lever, one end passing through a hole in P, the other forked to enclose sounding-line.

S, spiral spring keeping lever down.

B, messenger, which by its action on the lever raises pin P and inverts thermometer.

f is a catch which is caught by the tooth *t* on spring *s* when thermometer is inverted.

B′, messenger which is released by inversion of thermometer.

Fig. 8 shows the construction of the messengers B and B′.

Miller-Cassella maximum and minimum deep-sea thermometers (Buchanan's pattern) were also in use during the survey. In order to make a more profound study of temperature changes in a loch, an installation of electric thermometers, consisting of platinum resistance thermometers and a Callendar recorder, was set up at Fort Augustus, on Loch Ness. The recorder was placed in the boat-house of St Benedict's Abbey, and the thermometers were operated from the deck of a small yacht called the *Rhoda*, anchored in 300 feet of water and distant about 300 yards from the boat-house; a four-ply cable connected the recorder with the *Rhoda*. This same apparatus was later set up in Loch Garry by Mr E. M. Wedderburn in the spring of 1908. A sunshine receiver which could be lowered to any depth in place of the platinum thermometers also formed part of the equipment. Experiments were also made with a thermophone outfit, purchased in America, for recording the temperature.

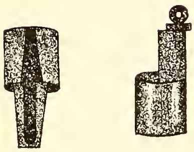


Fig. 8.

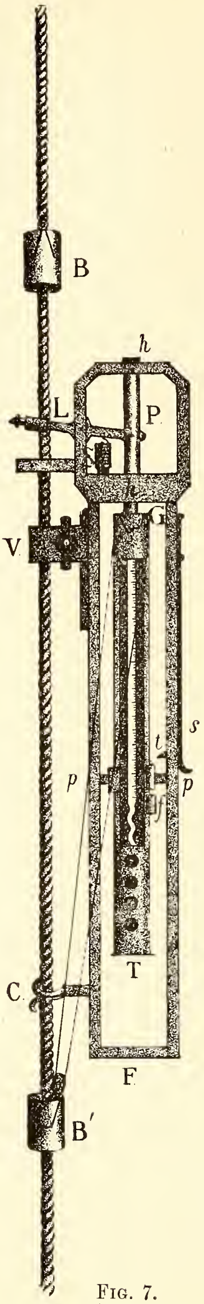


Fig. 7.

Electrical Experiments.—Advantage was taken of Lake Survey facilities to make some experiments on a point of theoretical importance, viz. the ionisation of air when surrounded by thick layers of water. A charged electroscope was immersed in Loch Ness at various depths, and the rate of leakage of the charge under these conditions was compared with the rate in ordinary circumstances.

This electroscope consists of a copper cylinder, containing a brass conductor, insulated by being supported on a quartz rod, and having at its upper end a slight brass rod, carrying a gold leaf, the deflection of which indicated the leak of the electrical charge. The experiments showed that, by surrounding the electroscope-case with a layer of water 120 feet thick, the conductivity, and therefore the ionisation, of the contained air is reduced, but not to less than 75 per cent. of the value which it has when the instrument is standing on dry land.

Seiches.—The first authentic seiche recorded in Scotland was observed by members of the Lake Survey staff in May 1902, while sounding Loch Treig, the amplitude being measured by placing a foot-rule in the water. A Sarasin limnograph was purchased in 1902, and set up at Fort Augustus, on Loch Ness, in June 1903. A second Sarasin limnograph was purchased in 1904; while in 1905 Professor Chrystal introduced several modifications, and had an improved form of the instrument constructed for use on Loch Earn. A statoscope was also employed by Professor Chrystal in connection with his seiche work, as well as barographs and sensitive barographs. These instruments are described in Professor Chrystal's article forming part of this volume.

Transparency.—Systematic observations on the depth at which discs of various colours disappeared from view when immersed in the waters of Loch Ness were made in July, August, October, November, and December 1903, and January 1904. This depth for white discs varied from 14 feet on 27th August, after heavy rain during the night, to 24 feet on 4th August. On 27th October a white disc was visible to 16 feet, a yellow disc to 15 feet, and a blue disc to 12 feet. The yellow disc could not be distinguished from the white disc so soon as it had descended about a foot, and the blue disc appeared quite green at that depth.

Similar experiments were made in other lochs, but it was found that the transparency of the water varied so much, according as the rivers were in flood, and according to the development of the plankton, that these observations were continued only when local circumstances made it desirable.

Currents.—In his recent work on Loch Garry and Loch Ness, Mr Wedderburn has made use of an Ekman current meter.

Biological Observations.—On one occasion, the *Mermaid*, the steamer belonging to the Marine Biological Association of the West of Scotland, was hired for several weeks, and, being specially fitted for trawling and dredging operations, a minute exploration of the deep waters of Loch Lochy and Loch Ness was possible. The other lochs were explored from rowing-boats or small steam launches with the usual nets and dredges in use among naturalists, such as tow-nets made of coarse and fine materials, as well as the special nets designed by Apstein and Nansen. During his biological investigations, Mr James Murray established many temporary fresh-water laboratories, where microscopic work was carried on, and the same may be said of Mr George West with reference to his botanical work in connection with the survey.

Lake Deposits.—These were collected in a variety of ways, according to the depth and other conditions, and the quantity of the sample desired. For the most part the samples were obtained in long brass tubes about half an inch in diameter, attached to the lead of the sounding apparatus. When a section of the deposit was required, the tubes were arranged to project nearly two feet beyond a heavy lead, which forced the tube fully eighteen inches into the deposit in some instances, a section of that length being occasionally procured. These tubes had a valve at the upper end. As a rule the tube was much shorter, and a butterfly valve was at times placed at the lower end especially when there was reason to suppose that the deposit was sandy. A bucket dredge was used from a steam-yacht or rowing-boat when a large sample of the deposit was required.

APPENDIX I

I. The Secretary of the Royal Society of Edinburgh to the Secretary of H.M. Treasury

Royal Society of Edinburgh,
11*th July* 1883.

Sir,—In consequence of the investigations now being carried on with reference to the physical and biological conditions of the Scottish fresh-water lakes, and also because of the importance, in certain branches of geological inquiry, of knowing the form of the basins occupied by these lakes, it has been prominently brought under the notice of the President and Council of this Society, that no bathymetrical survey of these lakes exists.

I have, therefore, been requested by the President and Council to ascertain from H.M. Government if there is any probability of this work being soon undertaken, and, at the same time, to state that it would be a great satisfaction to the President and Council to learn that instructions had been issued by the Lords Commissioners of H.M. Treasury to the Officers of the Ordnance Survey, or of the Hydrographic Department of the Admiralty, to undertake a survey of a few of these lakes similar to the excellent ones already made of Loch Lomond and Loch Awe—say Lochs Morar, Maree, Lochy, Assynt, Shin, Tay, Ericht, Rannoch, Earn, Doon (in Ayrshire).—I am, etc.,

(Signed) P. G. Tait,
Secretary, Royal Society, Edinburgh.

II. The Secretary of H.M. Treasury to the Secretary of the Royal Society of Edinburgh

Treasury Chambers,
17th September 1883.

Sir,—With reference to your letter of the 11th of July last, and the reply from this Board, dated the 10th ultimo, relating to a proposal to execute a bathymetrical survey of certain fresh-water lakes in Scotland, I am directed by the Lords Commissioners of Her Majesty's Treasury to acquaint you that my Lords are informed that the nautical surveys of Loch Lomond and Loch Awe, referred to in your letter, were undertaken by naval officers in the interests of navigation, and that the same considerations do not apply to the other lochs, of which surveys are suggested in your letter.

My Lords are also informed that the proposed bathymetrical surveys do not come within the functions of the Survey Department of the Office of Works (late Ordnance Survey).

Under these circumstances, my Lords regret that they are unable to sanction the proposed surveys. I have the honour to be, etc.,

(Signed) Leonard Courtney.

III. Discussion in the House of Lords

In March 1884, in reply to Lord Balfour of Burleigh in the House of Lords, Lord Sudeley said:—

"In reply to the noble Lord, I have to state that the operations of the Ordnance Survey have been hitherto restricted to such portions of the ground in the vicinity of fresh-water pools, and inland sheets of water generally, as are above the lowest water-levels. It is quite true, as the noble Lord has stated, that Loch Lomond and Loch Awe were surveyed, but that was undertaken by naval officers in the interests of navigation. The Government consider that a bathymetrical survey of all the lochs of Scotland would clearly be outside the function of the present Ordnance Survey of Scotland, which is already completed. Even if it were desirable, as the noble Viscount [Bury] has suggested, men would be taken off their work in England and the southern counties to carry this work out, and the general survey would be very much delayed. Such investigation would, no doubt, be most interesting from a scientific point of view in certain branches of geological inquiry to ascertain the forms of the basins occupied by the lakes. The Government will give the suggestions made by the noble Lord full consideration, and there will be no objection to lay the papers on the table.

IV. The Secretary of the Royal Society of London to the Secretary of H.M. Treasury

The Royal Society,
Burlington House, *2nd May* 1884.

Sir,—The President and Council of the Royal Society have had under consideration a communication from the Royal Society of Edinburgh, from which it would appear that the Lords Commissioners of Her Majesty's Treasury have stated that they are unable to sanction a bathymetrical survey of certain of the Scottish lochs, as proposed by the Royal Society of Edinburgh.

I am directed by the President and Council of the Royal Society to assure my Lords that they fully share the regret expressed by the Royal Society of Edinburgh that my Lords should have arrived at such a decision.

Neither from a topographical nor from a geological point of view can the survey of the United Kingdom be considered complete so long as the depths of the several inland waters remain unknown, and the absence of adequate data, concerning not only the Scottish lochs, but other large inland waters of the United Kingdom, forms, and will continue to form, a very serious obstacle to geological research.

The President and Council do not desire to urge upon my Lords any elaborate surveys entailing a large expenditure. They have reason to believe that the most important objects of the proposed surveys would be gained if series of soundings were carried across the important lakes not yet bathymetrically surveyed, at moderate intervals in each case. The exact closeness of the lines of soundings and the interval between each two soundings in each line must, in great measure, be determined at the time of observation according to the results which are from time to time obtained ; but it has been suggested that lines of soundings at about a quarter of a mile interval, with soundings about 100 yards apart, would probably be found generally useful.

The President and Council venture to remind my Lords that the carrying out of such a bathymetrical survey is much facilitated by the fact that the contours of the lakes in question have all been already accurately laid down ; also that the inland waters of the continent have been carefully surveyed by the several European Governments ; and that, though in Scotland only Lochs Lomond and Awe have been surveyed (notwithstanding that some of the others are used for purposes of navigation), and the English lakes not at all, several of the Irish lakes were sounded by the Admiralty surveying officers in the years 1834–39 and in 1846.

The President and Council fully appreciate the difficulty which presents itself to my Lords in the facts that such bathymetrical surveys as those proposed do not fall within the province of the Survey Department of the Office of Works, and that, since the object sought is not one concerning navigation, they are foreign also to the duties of the Admiralty. The object, indeed, of the proposed survey may be most fitly spoken of as geological, but the Geological Survey has no means of carrying out such a work.

The President and Council would, however, venture to urge upon my Lords that the proposed survey, though of great scientific importance, is limited in scope and special in character, and so far not of a nature likely to establish an undesirable precedent, and they sincerely trust that my Lords may be led to reconsider their decision, and may see their way to make some arrangements by which a bathymetrical survey of the various inland waters of the United Kingdom not yet so surveyed may be speedily carried out.—I have, etc.,

(Signed) M. Foster,
Sec. R.S.

APPENDIX II

A small volume of press notices, pulpit references, and extracts from private letters, all bearing on the ice accident on Airthrey Loch and the death of Mr Fred. P. Pullar, was printed and privately circulated at the end of 1901. Memorial prizes were given at the High School at Stirling, extending over a number of years. Sir John Murray offered three memorial prizes of £50 each in connection with the Marine Biological Laboratory at Millport, in which Mr Fred. Pullar took a great interest. The following notice was written by Sir John Murray's secretary, who was much associated with Mr Pullar during his many visits to the *Challenger* Office in Edinburgh and his work in connection with the initiation of the Lake Survey :—

"The Late F. P. Pullar.

"A melancholy interest attaches to the paper on the Scottish Lochs which appears in this number of the *Geographical Journal* and *Scottish Geographical Magazine*, owing to the tragic death of one of the authors, Mr F. P. Pullar, since the paper was passed for press. On February 15, while several hundred persons were skating on Airthrey Loch, in the grounds of Airthrey Castle, near Bridge of Allan, the ice suddenly gave way, and a number of people were precipitated into the water. Mr Pullar, who was a strong, muscular young man and a powerful swimmer, at once rushed to the rescue of those who were immersed, plunging into the water and floating ice with his skates on. He successfully assisted three of them to land, and then went to the succour of a young lady who was in an exhausted condition. It is confidently asserted by spectators, some of whom were submerged in their efforts to assist, that he might easily have saved himself had he relinquished his burden : this he refused to do. He supported the young lady for some time, but before help reached them his strength failed, and they both sank, their bodies not being recovered till three-quarters of an hour afterwards. This sad event cast a gloom over the whole district, and great sympathy was expressed for his bereaved parents, and for his only sister, who had just left the ice before the accident occurred. On February 19 he was buried in Logie Churchyard, attended by an immense concourse of mourners, and amid every expression of sorrow and sympathy.

"Frederick Pattison Pullar was born at Bridge of Allan on the 20th December 1875, and was the only son of Laurence Pullar, Esq., of The Lea, Bridge of Allan, and nephew of Sir Robert Pullar of Perth. In his earlier years he was rather a delicate child, and much of his education was conducted at home under private tutors. Later on his health improved, and his education was continued at the Stanley House School, Bridge of Allan, and the High School of Stirling. Afterwards he attended the Glasgow and West of Scotland Technical College in Glasgow, where he exhibited a marked ability for mathematics, mechanics, and applied science generally. He ultimately entered his father's business, but devoted a good deal of his time to scientific pursuits and studies. By his frank and genial nature he became endeared to the large number of workpeople employed by the firm of Robert Pullar & Sons.

"About five or six years ago, while cruising in his father's yacht, the *Freya*, he, under the guidance of Sir John Murray, commenced to take an interest in oceanographical observations and problems, exhibiting a lively devotion to the practical work carried on at the Marine Biological Station at Millport. He enthusiastically embraced the study of meteorology, and established at his father's residence at Bridge of Allan a complete meteorological observatory, his instruments including deep earth thermometers. He became a member of the Royal Meteorological Society and of the Scottish Meteorological Society, sending in reports regularly to the last-mentioned Society during the past five or six years. He presented a complete set of meteorological instruments to the Scottish Hospital which proceeded to South Africa last year under Professor John Chiene. A room in his father's house was fitted up as his own private workshop, in which he had many ingenious and interesting mechanical, electrical, and photographic contrivances, together with considerable geological collections. He was an enthusiastic cyclist, and within the last year or two had three or four kinds of motor vehicles. He had an intimate knowledge of these machines, and his advice was frequently sought by automobilists; indeed, he proceeded to the scene of the disaster in a motor car, which was standing at the side of the loch when he met his death. He was an Associate of the Institution of Mechanical Engineers, and an active member of the Automobile Club.

"About three years ago, in conjunction with Sir John Murray, he undertook a systematic bathymetrical survey of all the lochs of Scotland, and here his mechanical knowledge and inventive genius were at once exhibited by the improvements he made in the apparatus for taking the soundings. A portable machine was constructed from his designs, which could be firmly and rapidly fixed to the gunwale of the boat from which the soundings were to be taken. He also carried out many improvements in the methods of taking temperatures by means of deep-sea thermometers, in the plungers used for procuring samples of the deposits, and in the apparatus for the capture of organisms at intermediate depths. At the time of his death, among other improvements, he had in contemplation the construction of a motor engine which could be applied to the propulsion of both a car and a boat, so that he might carry with him from his home a boat for taking soundings, transfer the engine to the boat, and re-transfer it when the work was finished to the car again. The publication of the results of the researches in the Scottish lochs was commenced last year, the first instalment, dealing with the lochs of the Callander and Trossachs district, being published in the *Geographical Journal* and *Scottish Geographical Magazine* in April last; and the present number contains a further instalment, dealing with the remaining lochs in the Forth basin. The survey of some other lochs has been completed, but the results are not yet in a state for publication.

" In September last Sir John Murray left Britain for the purpose of carrying out explorations on Christmas Island, in the Indian Ocean, and it was arranged that the paper in this Number should be put into form and passed for press by Mr Pullar, with assistance in the *Challenger* Office. Sir John Murray returned to London on the evening of February 16, and on arrival at his hotel was handed a telegram announcing the death of his young friend on the previous day. They had made arrangements to devote most of the coming summer to the sounding of the lochs, with a view to the speedy completion of the entire survey: this important work will necessarily be interrupted by Mr Pullar's lamented death.

"Mr Pullar was elected a Fellow of the Royal Geographical Society in 1896, and he was also a Fellow of the Royal Scottish Geographical Society; last month he was admitted to the Fellowship of the Royal Society of Edinburgh.

"Mr Pullar was beloved by all who knew him. He was a man of great bodily and mental activity, lively disposition, generous and brave, knowing no fear. His friends were justified in believing that a great future lay before him. His promising career has been cut short by an act of devotion. He sacrificed his life in an heroic endeavour to save the life of another.

His life was gentle; and the elements
So mix'd in him, that Nature might stand up
And say to all the world, 'This was a man!'

"James Chumley.

"Challenger Office,
"Edinburgh, 27*th February* 1901."

APPENDIX III

Copy of Resolution passed by the Council of the Royal Society of London, June 1901

Mr Teall informed the Council that a number of Fellows and others interested in the subject had heard a statement by Sir John Murray with reference to a bathymetrical, physical, and biological survey of the fresh-water lakes of Great Britain and Ireland. It appeared that the Council had urged the importance of a bathymetrical survey of the principal fresh-water lakes of the country in a letter to Her Majesty's Government, dated 2nd May 1884, and that a survey on the lines therein indicated had been commenced, so far as Scotland was concerned, by Sir John Murray and Mr F. P. Pullar, but had been unfortunately interrupted by the accidental death of the latter gentleman. Mr Laurence Pullar (the father of Mr F. P. Pullar) had now intimated to Sir John Murray that he was willing, on certain conditions, to set aside a sum of money to enable this survey to be completed, and to be extended to all inland bodies of water. The conditions were as follows :—

(1) That there was little likelihood of this survey being undertaken by any of the Government departments.

(2) That Sir John Murray would himself undertake the general superintendence of the survey and the publication of the results.

(3) That, in the opinion of the Council of the Royal Society, it was important from a scientific point of view, in addition to the bathymetrical survey recommended in their letter of 2nd May 1884, to undertake at the same time an investigation into the physical and biological conditions of the fresh-water lakes.

As soon as the Council had declared their opinion, Sir John Murray was prepared to draw up an approximate estimate of the cost of the work for Mr Pullar's consideration.

It was resolved—That the Council confirm the opinion expressed in their letter to Her Majesty's Treasury of 2nd May 1884, as to the great scientific importance of a bathymetrical survey of the fresh-water lakes of the United Kingdom, and that they have learned with great satisfaction that arrangements are under consideration for the completion of the survey commenced by Sir John Murray and Mr Pullar, and are of opinion that the scientific value of the survey will be greatly increased if it embraces a study of the biological and physical conditions of the lakes.

Extract from a Minute of Meeting of the Council of the Royal Society of Edinburgh, held on 24th May 1901

The Council heard a statement from Sir John Murray with reference to a bathymetrical survey of the fresh-water lochs of Scotland, to the effect that Mr Laurence Pullar was willing, on certain conditions, to set aside a sum of money to enable the survey to be completed which had been commenced by Sir John Murray and Mr Pullar's son, Mr F. P. Pullar, but which had been interrupted by the unfortunate death of the latter gentleman by accident.

Mr Pullar was prepared to do this provided Sir John would himself undertake the general superintendence of the survey and the publication of the results ; provided, also, that the Council still regarded such a survey as important from a scientific point of view, and that it had been, and was likely in future to be, satisfactorily carried out on the lines suggested by the Council in the year 1884.

Sir John had been requested to prepare an approximate estimate of the cost of completing the survey for Mr Pullar's consideration, and he now asked the Council for suggestions as to any scientific observations that might with advantage be undertaken in connection with the survey. There was much discussion with regard to researches which might be carried out in fresh-water lochs, and Sir John was asked to assure Mr Pullar that the Council learned with much satisfaction that arrangements were in contemplation for carrying to a successful completion the admirable survey which had been commenced by Sir John and Mr Pullar's son, Mr F. P. Pullar, who was a member of the Society, and whose death they all deplored.

Conference of the British Association, September 1901

At the meeting of the British Association in Glasgow in September 1901, the President of the Geographical Section (Dr H. R. Mill) was enabled to announce that definite arrangements had been made to carry on the work. A conference of the Geographical, Geological, and Zoological Sections was held on 16th September, 1901, for the purpose of considering the scheme of the survey ; the discussion was taken part in by Dr Mill, Professor Bonney, Dr John Horne, Mr Isaac Thompson, Colonel Johnston, Mr Ben. N. Peach, Mr R. M. Clark, Professor Watts, Mr Barrow, Mr Cunningham Craig, Mr Dickson, Dr Fullarton, Mr W. S. Bruce, Mr Greenly, and the Rev. Frank Knight, and many valuable suggestions were thrown out as to the scope of the work. At the conclusion of the discussion, Dr Horne formally moved, on behalf of the meeting, the great gratification they all felt that this investigation should be carried out by means of the munificence of Mr Pullar, and under the administration of Sir John Murray ; the resolution was seconded by Mr Peach, and unanimously adopted.

APPENDIX IV

Books of Council and Session

Extract Registered Trust-Deed by Laurence Pullar, Esq., in favour of Robert Jenkins and Others

At Edinburgh the Twenty-fifth day of October One thousand nine hundred and one the Deed hereinafter engrossed was presented for registration in the Books of the Lords of Council and Session for preservation and is registered in the said Books as follows :—

I, Laurence Pullar of The Lea, Bridge of Allan, Considering that in or about the year Eighteen hundred and eighty-four the Royal Society of London and the Royal Society of Edinburgh addressed communications to her late Majesty's Government urging the importance of a bathymetrical survey of the principal fresh-water lakes of the United Kingdom, and that a survey on the lines indicated in these letters was commenced, so far as regards Scotland, by Sir John Murray, K.C.B., and my son, the late Frederick Pattison Pullar, but that the said survey was interrupted by the accidental death of my son through drowning on the fifteenth day of February last ; and considering that both of said Societies recently passed resolutions to the effect that the completion of the said survey is a matter of great scientific importance, but notwithstanding this there is little likelihood in present circumstances of the survey being taken up by any of the Government departments ; and considering that I have now resolved, as a memorial of my son, to provide the Funds which I am advised will be required for completing the said survey and publishing the results thereof—a work which my son had much at heart: Therefore I do hereby undertake forthwith to invest in the names of Robert Jenkins, Agent of the Union Bank of Scotland, Bridge of Allan, John Blair, Writer to the Signet, Edinburgh, and myself, the sum of Ten thousand pounds, such sum to be invested in the purchase of Consolidated Stock of the United Kingdom (Consols), which Consolidated Stock and any investment or investments that may from time to time be substituted for the same, and the interest or other annual income of such Consolidated Stock or other investment or investments, I direct shall be applied by the said Robert Jenkins, John Blair, and myself, and the survivors and survivor, or by such other person or persons as may from time to time be assumed into the Trust hereby created (all of whom are hereinafter included under the expression "the Trustees") as follows: (First) In paying all charges which may be incurred in the administration of the Trust, including in such charges all travelling and personal expenses which the Trustees may incur in attending meetings or otherwise in connection with the business of the Trust; (Second) In carrying on and completing or providing for carrying on and completing the said survey, being a bathymetrical survey of the principal fresh-water lakes of the United Kingdom, including an examination into the biological and physical conditions of the lakes, and in publishing the results of such survey and examination; Declaring that while I hereby give to the Trustees full powers to arrange for the conduct of the said survey and all matters connected with or incidental thereto, it is my special desire that they shall commit to the said Sir John Murray, so long as he is willing to undertake the same, the superintendence of the work and the publication of the results, and the disbursing of all outlays in connection therewith. And (Third) In paying to myself or my executors the balance, if any, of principal and income which may remain after fulfilling the foregoing purposes. And I hereby provide and declare that if I should die so soon after the delivery of these presents as to render Government Duties exigible on the Fund hereby settled, my executors shall be bound to pay such Government Duties and so free and relieve the Trustees thereof; And I also provide and declare that the Trustees shall have all the powers, privileges and immunities of gratuitous Trustees according to the law of Scotland, and in addition thereto the following powers and immunities, viz. power to appoint such officers, including any one or more of their own number, as they may consider necessary for executing or carrying out the work or administration of the Trust, and to pay such officers such salaries or other remuneration as they (the Trustees) may from time to time consider proper, also power from time to time to make such arrangements and lay down such rules as may in their opinion be requisite or expedient for securing the convenient and efficient carrying out of the work of the Trust; And I further provide and declare that the Trustees shall be the sole judges as to when the Trust purposes have been fulfilled; and that they shall not to any extent or in any way be responsible to me or to my heirs or executors, or to any other person or to any society or others whatsoever, for the proper execution of the work of the said survey or for any operations, matters or things in connection therewith or for the safety of the certificates, bonds or other documents which may from time to time be held for the Trust Funds, or for the securities or investments upon which the Funds may from time to time be invested or lent out, or for any depreciation in the value of the investments, or for the honesty or solvency of those to whom the same may be entrusted. And I consent to registration hereof for preservation; In Witness Whereof these presents written on this and the preceding page by William Blacklock, Clerk to Davidson & Syme, Writers to the

Signet, Edinburgh, are subscribed by me at Perth on the thirtieth day of August in the year Nineteen hundred and one before these witnesses James Morison, Accountant, Perth, and James M'Currach, Clerk to J. & R. Morison, Accountants, Perth. (Signed) Laurence Pullar, James Morison, Witness, James M'Currach, witness.

We, Laurence Pullar, Robert Jenkins and John Blair, all designed in the foregoing Trust Deed, do hereby respectively accept the office of Trustee thereby conferred on us ; In Witness Whereof these presents written by the before-designed William Blacklock are subscribed by us all at Edinburgh on the twenty-fifth day of October in the year Nineteen hundred and one before these witnesses Robert Connon and David Porter, both clerks to the also before-designed Davidson & Syme. (Signed) Laurence Pullar, Robt. Jenkins, John Blair, Robert Connon, Witness, David Porter, Witness.

Extracted from the Register of Deeds, etc., in the Books of Council and Session on this and the eight preceding pages by me, Keeper of said Register.

(Signed) J. A. Cameron.

(On 8th June 1903 Mr John Blair, W.S., died, and in April 1904 his son, Mr William Blair, W.S., was assumed Trustee in his stead.)

APPENDIX V

I. Letter from the Director of the Ordnance Survey

Ordnance Survey Office,
Southampton, *17th October* 1901.

Dear Sir,—With reference to your letters of the 9th and 12th instant, the Board of Agriculture has sanctioned the issue to you of two copies of the 6-inch, and one copy of the 1-inch map of the districts in which lakes are situated, one copy of the former to be returned to this Department with the depths of the lakes laid down on it, with a view to the lake contours being shown on the Ordnance Survey maps.

As soon as you are ready to receive any of these maps they will be sent to you, if you will kindly indicate those you wish to have first.

With regard to the transfers you desire, the copyright in the Ordnance Survey maps is vested in the Controller, Stationery Office, to whom formal application should be made for permission to reproduce or reduce, according to circumstances, the Ordnance Survey maps for insertion in your publications. If he gives the sanction required, I am authorised to supply to you transfers from the 6-inch scale maps.—Yours very truly, (Signed) Duncan A. Johnston,
Colonel.

Sir John Murray, K.C.B., etc.

II. Letter from the Controller of H.M. Stationery Office

Stationery Office,
5th December 1901.

Sir,—I have the honour to acknowledge the receipt of your letter of the 2nd instant, and to acquaint you that no objection will be raised by this Department on the ground of copyright to the reproduction of Ordnance maps, and publication if desired, in connection with the Lake Survey to be undertaken under the Pullar Trust, on the understanding that the source from which the reproductions are taken is quoted, and due acknowledgment made of the fact that the consent of the Controller of H.M. Stationery Office—in whom the copyright is by H.M. Letters Patent vested—has been obtained.

The consent of the Stationery Office to the supply of transfers by the Director-General of the Ordnance Survey is not necessary.—I have the honour to be, Sir, Your obedient Servant, (Signed) T. D. Pigott.
Controller.

Sir John Murray, K.C.B.,
45 Frederick Street, Edinburgh.

APPENDIX VI

List of Persons taking part in the Lake Survey

In addition to those enumerated below, we were especially indebted to the Lord Abbot, Father Odo Blundell, Father Cyril von Dieckhoff, and other members of the Benedictine Monastery at Fort Augustus for placing at our disposal the boat-house of the Monastery for the limnograph and apparatus connected with the electric thermometers, as well as for many other services.

Sir John Murray, K.C.B., F.R.S. } Directors.
Laurence Pullar, F.R.S.E., F.R.G.S. }
T. N. Johnston, M.B., C.M., F.R.S.E., zoologist.
James Murray, F.R.S.E., assistant zoologist.
John Hewitt, B.A., zoologist.
R. M. Clark, B.A., „
D. J. Scourfield, F.R.M.S., „
R. C. Marshall, M.A., „
C. Linder, D.Sc., „
C. H. Martin, B.A., „
James Parsons, B.A., chemist.
T. R. H. Garrett, B.A., geologist.
R. B. Young, M.A., B.Sc., „
L. W. Collet, D.Sc., „
G. West, botanist.
E. M. Wedderburn, M.A., LL.B., W.S., physicist.
E. R. Watson, B.A., B.Sc., „
J. H. M. Wedderburn, D.Sc., „
W. Watson, M.A., „
P. White, M.A., „
J. D. Fulton, M.A., B.Sc. „
J. Sutherland Black, M.A., LL.D., surveying work.
Sir John Jackson, LL.D., „ „
D. C. M'Intosh, M.A., „ „
James Walker, C.E., „ „
F. G. Pearcey, „ „
Prof. G. Chrystal, M.A., physical observations.
Prof. C. G. Knott, M.A. „ „
Father Odo Blundell, „ „
Father Cyril von Dieckhoff, „ „
Dr C. Wesenberg-Lund, biological observations.
Dr H. Bachmann, „ „
Mrs Bachmann, „ „

E. Blades, M.A., B.Sc., calculation work.		
Hugh Drummond, boatman.		
Allan Grant,	„	
William Fraser,	„	
Archibald Fraser,	„	
Philip Campbell,	„	
William Macdonald,	„	
A. Shennan,	„	
James Chumley, secretary.		
Robert Dykes,	office assistant.	
William Bee,	„	„
C. E. Wragge,	„	„
Miss Stewart,	„	„
Miss Drummond, M.A., B.Sc.	„	„
W. A. Caspari, Ph.D., chemist.		

SEICHES AND OTHER OSCILLATIONS OF LAKE-SURFACES, OBSERVED BY THE SCOTTISH LAKE SURVEY

By Professor G. CHRYSTAL, M.A., Sec. R.S.E., etc.

Historical

Every observer of Nature is aware how inconstant a thing is the level of a lake at any particular point of observation. Every passing puff of wind, a diving duck, a rising trout, a steady breeze, a storm-wind, a landslip, all affect it less or more. But there is one kind of denivellation which is more commonly present than any other, and yet is so apt to escape the ordinary observer unprovided with special apparatus, that until about six years ago it could not truly be said to be known in the lakes of Scotland. On an absolutely calm day, when there is neither wind nor rain nor snow, and the surface of a lake is mirror-smooth, and to the unaided eye seems absolutely motionless, careful measurement, even with such a rough apparatus as a foot-rule, will very often—in some lakes, nearly always—show that the surface of the water at any point is continually rising and falling with a rhythmical movement. Simultaneous observations at different parts of the shore will show that the whole of the water of the lake participates in this movement. The movement may be simply harmonic, *i.e.* like the swing-swang of a clock-pendulum; or it may be more complicated, and, although there may be synchronism between the movements in different places, these movements may not be everywhere alike. To take the simplest of all cases, there may be no vertical movement at a particular place (called the uninode), with vertical movements increasing in range[1] towards the end of the lake on one side of the uninode, and on the other side simultaneous vertical movements always in the opposite direction, increasing in range towards the other end of the lake. As will be explained

[1] By the "range" of a seiche at any point is meant the vertical distance between high and low water. Half this distance is called the "amplitude."

presently, these vertical movements of the water are accompanied by horizontal movements of even greater range, but these are much more difficult to measure, or even to detect. The lake oscillation thus roughly described is the simplest variety of what is called a Seiche. A seiche in general may be summarily described as a standing or stationary oscillation of the whole lake. As will be more fully explained presently, the word "standing" or "stationary" applies to the form of the surface, and indicates that there is no translation or progression of the wave-form as in an ordinary train of surface waves.

The word "seiche" has been used, and the phenomenon which it denotes known popularly, from time immemorial on the Lake of Geneva. The first accurately recorded scientific observation of a seiche seems to have been made by Fatio de Duillier, a well-known Swiss engineer, in 1730. In the *Scots Magazine* for 1755 (p. 593 and elsewhere) seiches are described, which were caused in several of the lakes of Scotland, and in particular in Loch Lomond, by the earthquake of Lisbon on the morning of 1st November 1755. The period of this seiche in Loch Lomond seems to have been about ten minutes, and its maximum amplitude 2½ feet. In his great monograph on the Lake of Geneva, vol. ii. p. 50, Forel gives an account of the earlier observations of seiches, and refers in particular to one observed at Kenmore on Loch Tay in 1784, which lasted several hours, having a period of seven minutes, and a maximum range of nearly 5 feet.

The seiches of the earlier observers were in all cases of exceptional amplitude, and seem to have been regarded as occasional phenomena due to exceptional causes. Even in comparatively recent times there appears to have been a belief that seiches were peculiar to the Lake of Geneva. It seems to have been J. P. E. Vaucher, Pastor, and Professor successively of Botany and Church History at Geneva, who, in a memoir written between 1802 and 1804, and published in the memoirs of the Physical Society of Geneva in 1833, first pointed out that seiches are not confined to Léman, but are to be found more or less in all lakes; that they may have all ranges up to 5 feet or more; and may occur at all seasons of the year, although their occurrence seems to be affected by the state of the atmosphere. He also pointed out that the range of the seiches in Léman increases towards its western end, and that the seiches at its eastern end are not more marked than those observed in other lakes.

But our really accurate knowledge of the phenomena of seiches dates from the commencement of Forel's own observations at the harbour of Morges, on the Lake of Geneva, in 1869. He may with justice be called the Faraday of seiches. He worked at first with a small portable apparatus (plemyrameter), and later (1876) with a self-registering limnograph installed at Morges, and a portable limnograph of simpler construction. In 1877 Plantamour established a magnificent self-registering limnograph at his villa at Sécheron, near Geneva, which has been in continuous operation since. In 1879 Sarasin devised his portable limnograph, with which observations were made at Tour de Peilz, Chillon, Rolle, and various other stations on Léman, and also upon other Swiss lakes. In 1880 the French Government engineers also installed a fixed limnograph at Thonon, with which observations have been made under the superintendence of Delebecque, Du Boys, and Lauriol.

During the last twenty years a large number of enthusiastic observers have followed the lead given by Forel and his fellow-countrymen; and we have now a great mass of information regarding the seiches in lakes in various parts of the world,[1] from the 15-hour seiches observed by Henry in Lake Erie, which is 396 km. long, to the seiches of 14 seconds observed by Endrös in a small pond whose length was only 111 m.

Systematic observation of seiches in the lakes of Scotland is of very recent origin. On 22nd May 1902, Dr Johnston and the late Mr J. Parsons, using merely a foot-rule, made a determination of the uninodal period of Loch Treig. In the same year Mr James Murray made similar determinations for Lochs Laggan, Arkaig, Morar, Fada, Maree, and Chroisg, and Mr J. Hewitt for Lochs Shiel and More. Mr Murray also detected the binodal seiche of Lochan Fada, and in 1903 Mr T. R. H. Garrett obtained a good approximation to the uninodal period of Loch Ness. All these observations were made with a foot-rule, and make no pretence to great accuracy. The uninodal periods found, some of which are given in the table below on p. 53, varied from 9 min. for Loch Treig to 31 min. for Loch Ness, and the ranges from 0·38 cm. to 3·7 cm.

In June 1903 a self-recording Sarasin limnograph was erected at Fort Augustus under the superintendence of Mr E. M. Wedderburn, who was afterwards assisted in the observations by Messrs James Murray and E. R. Watson. In May 1904 a Dines-Shaw microbarograph, provided by the Moray Fund of the University of Edinburgh, was set up alongside of this limnograph. The observations were continued till May 1905, the instruments having been in the charge of the monks of the Order of St Benedict from October 1904 to May 1905. This valuable series of observations has not as yet been exhaustively discussed, but Mr Wedderburn has deduced from them

[1] See the extension of Forel's bibliography appended to my paper on the Hydrodynamical Theory of Seiches, *Trans. Roy. Soc. Edin.*, vol. xli. p. 599, 1905; also, for the most recent information, an excellent paper by Halbfass, "Der heutige Stand der Seiches-Forschung," *Zeitschr. Ges. Erdk. Berlin*, 1907, p. 6.

the values of the uninodal and binodal periods of Loch Ness, which are given in the table on p. 53 below.

During a week in July 1904, Mr E. M. Wedderburn made observations on Loch Earn with a roughly constructed self-recording limnograph of his own design. The results obtained were somewhat fragmentary, but they sufficed to suggest the very successful series of observations afterwards made on the lake in question.

In October 1904 Mr Wedderburn installed a Sarasin limnograph on Loch Treig, and with the assistance of Mr Duncan Robertson, one of Sir John Stirling Maxwell's gamekeepers, continuous observations were carried on until the well of the limnograph was destroyed by a storm in the following month. From these observations were deduced the two periods for Loch Treig given in the table on p. 53 below.

In 1903 my attention was drawn to the subject of lake oscillations by Sir John Murray, and on 16th February of that year, at a meeting of the Royal Society of Edinburgh, I gave at his request an address chiefly intended to furnish a seiche-programme for the Scottish Lake Surveyors. In this address I gave a summary of the mathematical theory of stationary lake oscillations, which was afterwards published as a memoir "On the Hydrodynamical Theory of Seiches," *Trans. Roy. Soc. Edin.*, vol. xli. p. 599, 1905. In a memoir "On the Calculation of the Periods and Nodes of Lochs Earn and Treig, from the Bathymetrical Data of the Scottish Lake Survey," *Trans. Roy. Soc. Edin.*, vol. xli. p. 823, 1905, Mr E. M. Wedderburn and myself applied the hydrodynamical theory to calculate the seiche periods of these two Scottish lakes. In what follows these papers will be denoted by H.T.S. and C.P.N. respectively.

In 1905 I organised an investigation of the seiches of Loch Earn, to be accompanied by observations for comparison on Lochs Tay and Lubnaig. As the greater part of the rest of this paper is simply a summary of the methods and results of this investigation, I need merely say here that Mr James Murray, under my direction, was in charge of the work during the months of June and July, and that I was myself in immediate command during August and September, when I had the valuable assistance of Messrs P. White and W. Watson. In aid of this work, in addition to the funds of the Lake Survey, we had a small grant from the Government Fund for Scientific Research. We also had the advice and assistance of Mr W. N. Shaw, Director of the Meteorological Office, London, which were of great help on the meteorological side of our enterprise. The detailed report on this work ("An Investigation of the Seiches of Loch Earn by the Scottish Lake Survey") has now been published in the *Trans. Roy. Soc. Edin.*, vol. xlv. p. 361, 1906, and vol. xlvi. p. 455, 1908. This report will hereafter be referred to as I.S.E.

The space at my disposal here will not permit me to enter into the history of recent seiche investigations outside of Scotland, although they have been many and important. For these I may refer the reader to the bibliography appended to H.T.S.; to the excellent article by Professor Halbfass,[1] the investigator of the Madüsee; and to an admirable review published in *Petermann's Geographische Mitteilungen*, Heft ii. p. 16, 1908, by Dr Anton Endrös, who is himself one of the most distinguished of modern seiche investigators.

Limnographic Apparatus used in the Survey of Lochs Earn, Tay, and Lubnaig

One of the simplest and most effective of the instruments for measuring the denivellation of a lake is the index limnograph, originally devised by Endrös. Fig. 9 shows the form used by the Scottish Lake Surveyors. The essential parts are the float, and its sheltering well and access tube; a piece of fly-fishing line, passing from the float over a small pulley to a counterpoise; and an index, attached to the pulley, which indicates on a scale, that can be made as large as may be desired, the rotation of the pulley, which is of course directly proportional to the rise or fall of the float. The observer is provided with a piece of squared paper, the horizontal divisions of which represent half-minutes, and the vertical divisions the readings on the limnograph scale. An observation is made every half-minute, and a corresponding dot made on the recording paper. Through these dots is drawn with a free hand a curve which is called a "limnogram."

For many purposes it is desirable to have a continuous record, extending over a considerable time, for both night and day. For this purpose a special instrument was constructed after my design, which is called the "waggon recorder" (fig. 10). It is really a combination of the essential principles of the older limnographs of Plantamour and Sarasin. The string of the index limnograph is replaced by a Chesterman's steel tape, which passes horizontally over two pulleys, between which it drags backwards and forwards a little waggon carefully mounted by means of three wheels, which run two on one and one on another of two parallel rails. The waggon carries an ordinary stylographic pen, so mounted as to write on a long strip of paper which is moved horizontally by rollers driven by clockwork. As the motion of the paper is perpendicular to the motion of the pen, caused by the rise and fall of the water, the result is the same as before, only the work and the patience are now transferred from the

[1] See footnote on p. 31.

living observer to the waggon and the clock, and the record is absolutely continuous.

Figs. 11 and 12 will give an idea how the instrument is mounted by the lake-side, so as to resist the combined efforts of rain, wind, and waves to make an end of the observations of the limnographer.

Fig. 9.

The precautions taken were by no means unnecessary, for, as already mentioned, in November 1904 part of the Sarasin limnograph under Mr Wedderburn's charge on Loch Treig was destroyed during a storm, and there were times during the months of August and September 1905 when I trembled for the security of our installations.

Fig. 13 shows a form of limnograph which I devised for investigating the nature of the embroidery on the limnograms. It consists essentially of a large and very sensitive barograph (Richard statoscope), DSS, which is connected with a closed well, W, placed partly in, partly out of, the lake. The rise and fall of the lake-level causes a corresponding rise and fall of the water-level inside this closed well, thereby increasing and diminishing the air-pressure in the

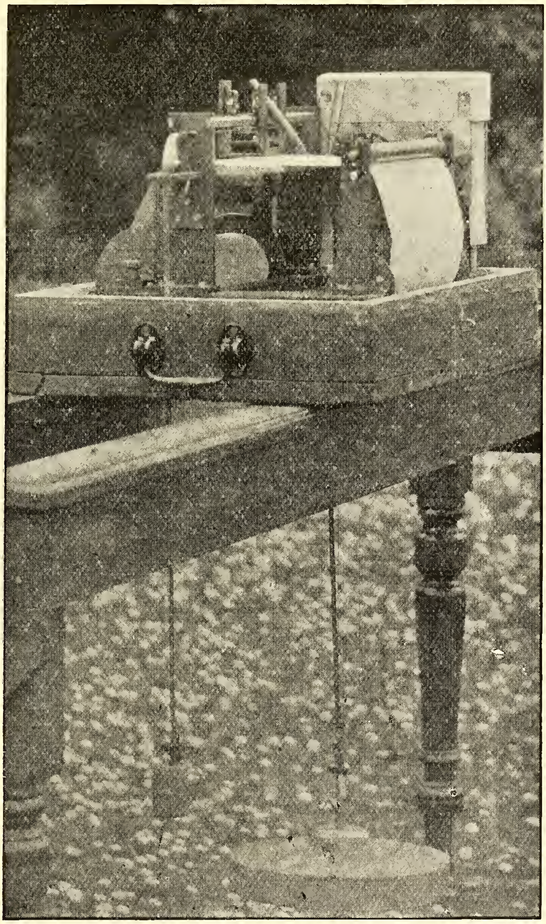


Fig. 10.

cylinder, SS, into which are fixed the barograph capsules, which are thus compressed and extended like the bellows of a concertina. This compression and extension are transferred by a system of multiplying levers, working the pen which writes on the recording drum, D. The inertia of the working parts is very small, and the sensitiveness to alteration of pressure is fifteen or twenty times that of an ordinary mercury barometer. The instrument will therefore show quite plainly extremely small denivellations of the lake, and it can be made more or less sensitive by increasing or diminishing the diameter of the well. By merely turning the stopcock, and shutting off the communication with the well, we turn the instrument into a very sensitive barometer. The curve which it traces is thus changed, at a moment's notice, from a limnogram into a barogram, so that we can alternately record the

Fig. 11.

denivellation of the lake and the variation of the atmospheric pressure. If, instead of closing the stopcock C, it is left open, and the other end of the tube CC allowed to communicate with the open air through a capillary tube of properly chosen length and bore, the statoscope will act exactly like the Dines-Shaw microbarograph, with the advantage of a larger time-scale. The instrument itself I call a statolimnograph.

In addition to the statolimnograph, and four index limnographs, which were worked at constantly varying points, we had three fixed

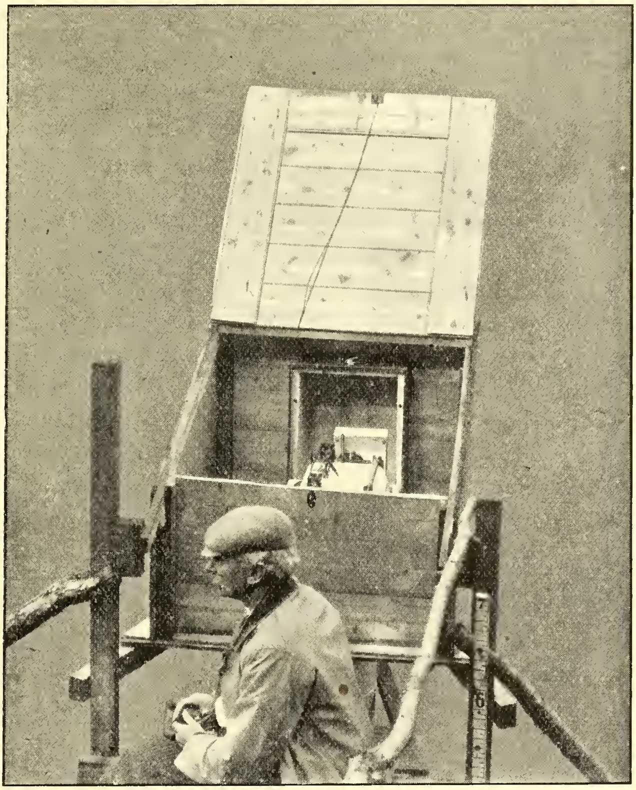


FIG. 12.

limnographs—one near St Fillans (the waggon recorder), one near the binode (a Sarasin), and one near the uninode (a Sarasin). The

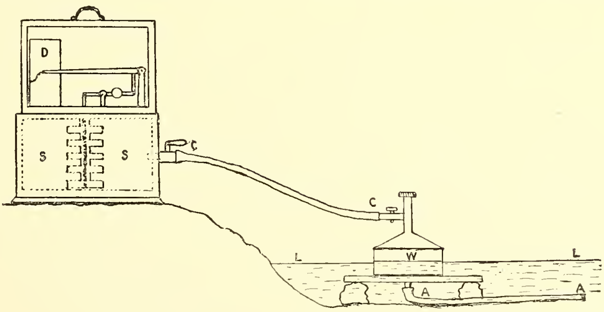


FIG. 13.

last, unfortunately, was useless for a good part of the time, partly because its clock went out of order, partly because the Sarasin gearing proved too crude to deal with the delicate seiches of Loch Earn; and it was near the end of the time at my disposal before we were able to remodel it and the other Sarasin on the plan of the waggon recorder which worked so well at St Fillans.

Besides the limnographic apparatus, we had quite a battery of meteorological instruments—three microbarographs of the Dines-Shaw pattern, and a Dines pressure anemograph, which was installed near my house at Ardtrostan, and worked beautifully. One of the microbarographs was placed at Ardtrostan, one at the west end of Loch Earn, and one at Killin, at the west end of Loch Tay. At each of these places were also ordinary barographs, which were controlled by means of observations made twice a day with a standard barometer in charge of Messrs White and Watson. As the observations made with the triangle of microbarographs were found to possess a certain amount of independent meteorological interest, an account of them was published separately in a paper "On the Theory of the Leaking Microbarograph, and on some Observations made with a Triad of Dines-Shaw Instruments," *Proc. Roy. Soc. Edin.*, vol. xxviii. p. 437, 1908.

Various Causes of the Denivellation registered in a Limnograph

The ordinate of the limnogram taken at any particular station on a lake shows the height at different times of the lake-surface at that station above a certain arbitrarily chosen level. Retardation and damping due to the instrument being allowed for, the limnogram gives the total denivellation at the station due to all causes whatsoever.

The examples reproduced in fig. 14 are from Loch Earn, all taken by the waggon recorder near St Fillans. They give a good idea of the great variety in the form of the limnographic record, and of the complexity of the phenomena to be explained. The two upper curves are very smooth, and furnish excellent examples of what we call the configuration period of a dicrote seiche. The third curve is an example of the strongly marked embroidery which appears on the limnogram during stormy weather. The fourth curve is an example of a sieche in moderately calm weather broken by varying weather conditions. The fifth curve, except for the slight wind embroidery, gives an example of an almost pure sinusoidal curve; it was taken near one of the points on the lake, which we shall presently define as binodes, and furnishes a test of the mathematical theory.

Among the various causes which may affect the level of a lake, the following may be enumerated:—

1. **Volume Denivellations.**—Caused by precipitation or evaporation. These are usually of slow variation, easily traced to their causes, and evidently not directly concerned with seiche phenomena.

2. **Persistent Wind Denivellations.**—Due to the heaping up of the water at one end of a lake, or in shallow places, where the bottom friction prevents the development of an under return current to counteract the surface wind current. These denivellations are slow and irregular in their variation, and again easily traced to their cause.

3. **Fluctuating Wind and other Denivellations.**—Due to the propagation of trains of waves on the surface of the lake by the

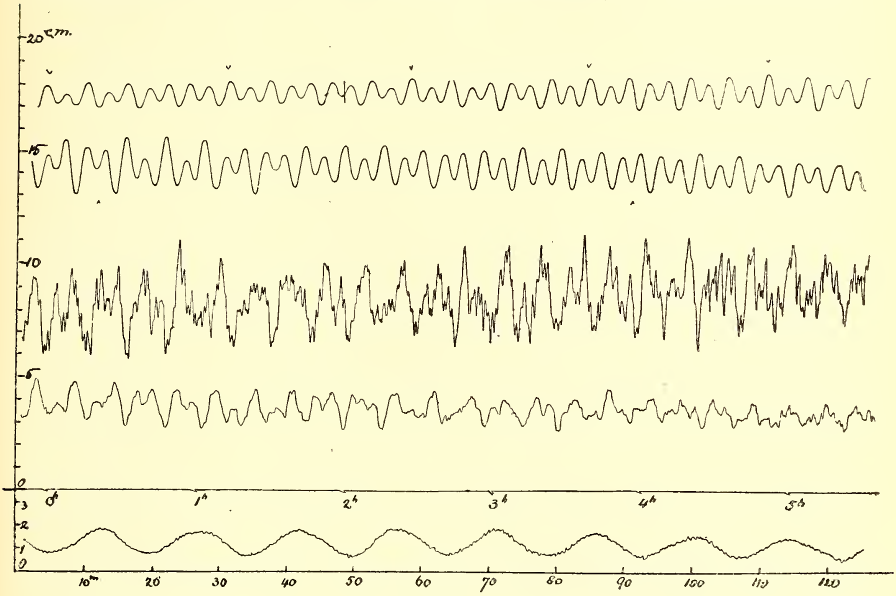


Fig. 14.

passage of wind-squalls, and associated with the rapid variations of wind pressure shown by the self-registering anemograph. Such wave trains may also be started by passing steamers or other accidental causes.

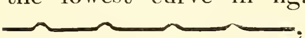
4. **Swell Denivellations.**—After a persistent wind has blown for some time over a stretch of water of a certain length, a kind of dynamical equilibrium is established between the wind and the water, and the surface becomes covered with more or less regular trains of progressive waves. Owing to reflection at banks and retardation at shores and shallows, and also to unsteadiness of the wind, there is an interference of superposed trains, which spoils the wave pattern, and prevents absolutely regular periodicity in the denivellation at any

given point. The general effect is, however, a fairly regular pattern of small progressive waves of apparently constant length, usually diversified by wave maxima at approximately equal intervals. This system persists for some time after the wind falls, and in this stage is usually spoken of as "swell."

5. **Seiche Denivellations.**—These are stationary oscillations of the whole lake, having nodes (*i.e.* places of no vertical motion), ventral points (*i.e.* places of no horizontal motion), and periods depending only on the configuration of the lake-basin.

The last three forms of denivellation—which for shortness we may call *solitary wave*, *swell*, and *seiche*—all make themselves felt on the limnogram; and it may be worth while to dwell for a little on the distinction between them, which is often imperfectly understood.

Solitary Wave.—Suppose water to be poured to a depth of about three inches into a shallow rectangular trough, say 6 feet 8 inches long and $8\frac{1}{2}$ inches broad.[1] If a vertical board nearly as broad as the trough be inserted at one end, and a moderately sudden sweep made towards the other end, a hump will be raised on the surface of the water, which travels along the trough without very rapid alteration of form, is reflected at the end, and travels backwards, and so on. Observation shows that the particles of water are affected by this wave only while the hump is immediately over them. If the trough were infinitely long, they would come to rest after the solitary wave had passed away. Each particle comes to rest in a position at, or at least near, its original one. It is the wave form, and not the constituent water, that really travels, as may be seen by watching a splash of red ink thrown on the top of the wave as it passes. Theory and observation agree in giving the formula $V = \sqrt{(gh)}$ for the velocity of the highest point of the solitary wave, where g is the acceleration due to gravity, and h the depth.

It is important to observe that a wave of this kind, travelling backwards and forwards in a lake of uniform breadth, depth (h), and length (l), would produce a periodic disturbance at one end of the lake having a period $2l/\sqrt{(gh)}$. It should be noticed, however, that the curve on the limnogram would not in general be a sinusoid, like the lowest curve in fig. 14, but something more of this shape: , where periods of positive denivellation alternate with periods of no disturbance.

Progressive Waves generated by a Wind Current.—Next suppose water to be poured into a tank 12 feet long, $2\frac{3}{4}$ inches wide, fitted with a parabolic bottom, concavity upwards, till the depth at

[1] The dimensions given here and in what follows are taken from apparatus actually used in demonstrations during a lecture at the Royal Institution in London, much of which is reproduced in this article.

the middle is 4 to 6 inches. Suppose the greater part of the top of the tank to be covered over and a current of air to be blown along the surface. So long as the current is below a certain strength (0·45 mile an hour), there is no disturbance of the mirror surface; above that limit, and under a velocity of about 2 miles an hour, there is disturbance which is transient, *i.e.* does not long survive the disturbing causes (cats'-paws). For higher current velocities a regular train of so-called progressive waves is formed, which increase in height and in length as we go down the wind. In nature, the water is comparatively calm at the windward end of the lake, but more—it may be very much—agitated at the other. Even at their greatest, these waves in such a tank as that above described are very short (say $\lambda = 0{\cdot}25$ foot); their period also is short (say $T = 0{\cdot}22$ sec.). By watching a thin stream of red ink dropped from a pipette into the water in the tank, it may be seen that the oscillatory disturbance, of which these progressive waves are the manifestation, dies away on descending from the surface downwards, and is not appreciable at any great depth. Apart from the drift current near the surface set up by the wind, the motion of the individual water particles is in closed elliptic orbits. From the formulæ

$$V = \sqrt{\left(\frac{g\lambda}{2\pi}\right)} \qquad T = \sqrt{\left(\frac{2\pi\lambda}{g}\right)}$$

it is easy to calculate the velocity of propagation and the period of these waves.

For Loch Earn, common values would be about $\lambda = 20$ feet, $T = 2$ sec., $V = 10$ feet per sec. $= 6{\cdot}8$ miles per hour.

Generation of a Seiche by Horizontal Stirring at the Nodes.—Following a method due to the two young experimenters, Messrs White and Watson, to whose results I shall presently refer, it is easy to start a seiche in a long parabolic tank such as described above. This is done by stirring horizontally in the middle of the tank, with a period of about 5 sec. In a parabolic tank this period happens to be independent of the depth of the water; in general it depends on the shape of the basin in which the liquid is confined and on gravity, but on nothing else. The result will be found to be a motion, quite different in kind from the two cases just described, called a pure uninodal seiche. It is a periodic wave motion, but the wave form does not travel as in the two former cases. At first sight it would appear as if the surface particles merely moved vertically upwards and downwards, except at one point called the node, where there is little or no perceptible vertical motion of the surface. In reality the water particles describe rectilinear orbits of various lengths, inclined at various angles to the horizon. These are drawn to scale for a selection of different particles in the middle part of fig. 15; the upper part of the figure is a similar diagram for a tank of rectangular longitudinal section. The nature of the motion at various places may be demonstrated by dropping in red ink as before. In the present case the whole of the water is in motion, and the striking thing is that all the water particles keep exact time, like a company of well-drilled soldiers. Each particle is at the end of its orbit at the same time; each at the arrow-marked end at the same time; and so on. This collaboration is expressed mathematically by saying that the particles are always in the same phase, although

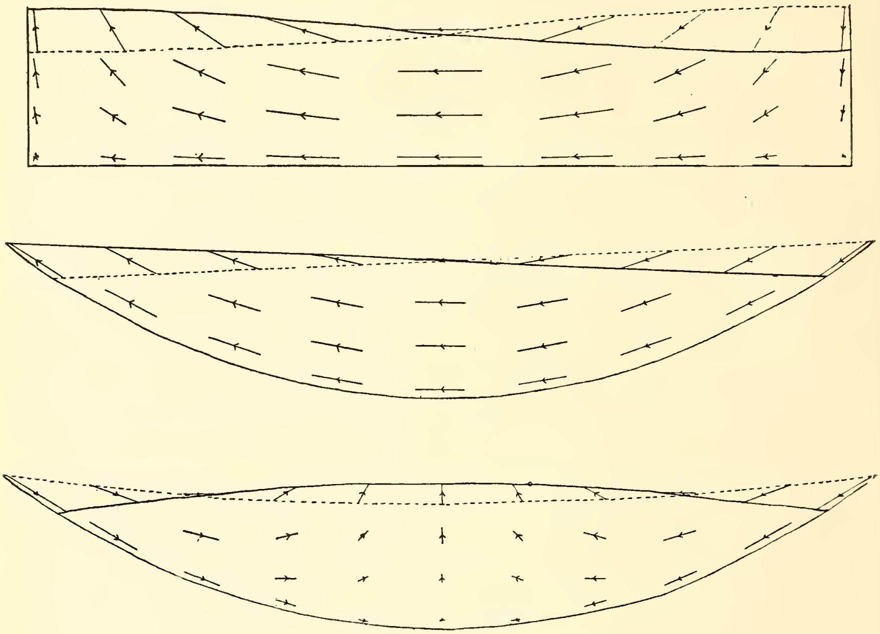


Fig. 15.

the directions and lengths of the orbits vary from point to point. It is a matter of wonder that this should be the case for two particles 12 feet apart in our experimental tank; but it seems well-nigh incredible, though unquestionably true, that the same holds good for two water particles at the two ends of the Lake of Geneva—that is to say, 45 miles apart. It was therefore not an obvious remark, but a brilliant generalisation, which Forel made long ago, when he asserted that the seiches of the Lake of Geneva were standing oscillations, similar in nature to the one which may be started in a 12-foot tank.

By stirring with a period of about $2\frac{1}{4}$ sec. at a distance from the end of our miniature lake $= 0{\cdot}21l$, a standing oscillation of another description is raised, with two nodes each somewhat nearer the ends of the lake than a quarter of its length, and a ventral point in the middle. At the ventral point the motion of the water is wholly vertical, whereas at the two nodes it is wholly horizontal. This kind of motion is called a pure binodal seiche. The orbits of the particles at various parts of the liquid will be understood from the lowest part of fig. 15.

With equal ease a trinodal seiche may be stirred up.

It should be noticed that the uninodal water surface for a parabolic lake is always a plane, which oscillates about the nodal line between the full-drawn and the dotted positions in fig. 15. For the same kind of lake the binodal water surface is a parabola, which varies in position and curvature between the dotted and full-drawn positions.

In the case of a lake of uniform depth, the corresponding surface curves are sinusoids, as shown in the upper part of fig. 15.

Hydrodynamical Theory

In a memoir (H.T.S.) already referred to I have discussed the theory of seiches in an elongated lake on the assumption that a seiche may be treated as a "long" stationary wave. So far as seiches of the lower nodalities are concerned, this amounts to assuming that the square of the ratio of the range of the seiche at the ends of the lake to the length of the lake is negligible.

From this discussion it results that :—

1. In any given lake, pure seiches of all degrees of nodality, *i.e.* uninodal, binodal, trinodal, etc., are possible; and any actual seiche is either one of these or a superposition of several of them. A compound seiche, which is a superposition of two pure seiches, we call a dicrote seiche; and so on, following the nomenclature of Forel.

2. When the lake is of uniform breadth and depth, the periods are proportional to—

$$\frac{1}{1}, \quad \frac{1}{2}, \quad \frac{1}{3}, \quad \frac{1}{4}, \ldots \quad \text{(harmonic series)}$$

and the quarter wave length, *i.e.* the distance from each node to the next ventral point, is the same all over.

3. When the depth or breadth, or both, varies, the periods are in general no longer commensurable. Thus, for a *complete parabolic lake* the ν-nodal period is given by $T_\nu = \pi l / \sqrt{\{\nu(\nu+1)gh\}}$, where l is the length and h the maximum depth ; that is to say, the periods are proportional o

$$\frac{1}{\sqrt{(1\times 2)}}, \quad \frac{1}{\sqrt{(2\times 3)}}, \quad \frac{1}{\sqrt{(3\times 4)}}, \quad \frac{1}{\sqrt{(4\times 5)}} \quad \ldots$$

Again, for a lake whose longitudinal section (or normal curve) is a certain quartic curve, $T_\nu = \rho / \sqrt{(\nu^2+\epsilon)}$, where ρ and ϵ depend on the dimensions of the lake, and ϵ may be positive or negative, according to circumstances.

4. Hence it follows that the ratio of the binodal to the uninodal period may be less than, equal to, or greater than $\frac{1}{2}$, according to circumstances—a fact which seems to have puzzled seiche observers considerably. Indeed, I have shown that quartic lakes can be imagined in which the periods T_1, T_2, T_3, . . . may be as nearly all equal as we please.

5. The positions of the nodes are given by the roots of certain equations $\chi_\nu(x)=0$; and the ventral points by the roots of certain other equations $\phi_\nu(x)=0$. The roots of these equations interlace with each other; but the quarter wave lengths are not, in general, equal, as in the case of the lake of uniform breadth and depth.

6. The following tables, founded on calculations partly by myself (H.T.S.), partly by Dr Halm, will convey a clear idea how the ratios of the periods and the positions of the nodes may vary in lakes of uniform breadth but different shapes of floor:—

Lake with	T_2/T_1.	T_3/T_1.	T_4/T_1.
concave parabolic floor . .	·577	·408	·317
plain horizontal ,, . .	·500	·333	·250
convex parabolic ,, . .	·472	·312	·234
convex quartic ,, . .	·447	·293	·218

Positions of Nodes

Lake with	Uninodal Seiche.	Binodal Seiche.	Trinodal Seiche.	Quadrinodal Seiche.
concave parabolic floor . .	$w=0$	±·577	0; ±·775	±·340; ±·862
plain horizontal ,, . .	0	±·500	0; ±·667	±·250; ±·750
convex parabolic ,, . .	0	±·473	0; ±·632	±·224; +·717
convex quartic ,, . .	0	±·447	0; ±·600	±·202; ±·684

where w is the distance of a node from the centre of the lake, half the length being taken as unity.

7. A shallow or other obstruction, or a deep near a node, greatly affects the corresponding period, a shallow increasing the period, a deep decreasing it. Also a shallow attracts the node towards itself, and a deep repels it. Thus, for example, the binodes in a parabolic lake are nearer the ends than in a rectangular one.

If the obstruction at a node is very great, it may render the corresponding seiche unstable, or prevent its occurrence altogether. This explains the absence in certain particular lakes of certain seiches of the theoretically possible series.

8. When the breadth and the form of the transverse section of an elongated lake vary as well as the depth, provided these variations are not too abrupt, it can be submitted to calculation by introducing two new variables, viz., σ, which is the product of the area of the transverse section by the breadth of this section at the surface; and v, which is the area of the surface of the lake between the trace on the surface of the transverse section corresponding to σ, and any other similar line chosen for reference. In order to submit the lake to calculation, its line of maximum depth is taken and laid out straight, and practically the lake is treated as if it were a lake of uniform breadth and rectangular cross section, whose longitudinal section is the curve, the abscissa and ordinate of any point on which are v and σ respectively. This curve I call the *normal curve* of the lake.

Judging by the results for Lochs Treig and Earn, these assumptions are sufficiently correct for ordinary concave lakes at least.

9. It will be obvious that a seiche, properly so called, differs essentially from an ocean tide. The origin of a seiche, and the absolute and relative magnitudes of the pure seiches of which it is composed, no doubt depend on external circumstances; but the periods and the positions of the nodes of the component seiches depend merely on the configuration of the lake-basin, and on the surface-level of the water at the time. In a tide, on the other hand, the periods are dependent on external disturbing agencies, chiefly the sun and moon. In the language of physicists, a seiche is a *free oscillation*; a tide a *forced oscillation*.

Du Boys' Theory.—My predecessor in the mathematical theory of seiches, M. Du Boys, gave, seventeen years ago, in his interesting "Essai théorique sur les Seiches," an approximate method for calculating the periods of a seiche. He treats the seiche as the interference of two solitary waves travelling backwards and forwards in the lake, the velocity of propagation being at each section that due to the greatest depth there. He thus arrives at the formula

$$T_\nu = \frac{2}{\nu}\int_0^l \frac{dx}{\sqrt{(gh)}}.$$

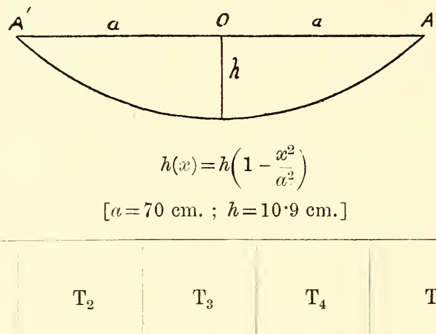
The symbol $\int_0^l \frac{dx}{\sqrt{(gh)}}$ simply means the time that a man would take to travel from one end of the lake to the other along the line of greatest depth, his speed at each point being that which a stone would have after it has fallen from rest through a distance equal to half the depth at that point.

This formula is exact for a lake of uniform breadth and depth, but errs in excess for a lake having a concave, and in defect for a lake having a convex, bottom. But the approximation becomes better as the nodality rises; and, for that and other reasons, his rule is very useful in limnographic calculations.

Experimental Verification of the Hydrodynamical Theory.—In order to satisfy myself of the applicability of the theory of long waves to seiches in an elongated lake, I asked Messrs White and Watson, two of Professor Macgregor's students, to make for me a series of experiments on waves in a tank fitted with various longitudinal sections. The conditions in the laboratory experiments were very much less favourable for the theory than in actual lakes. For example, the ratio of the depth to the wave length in the experiments ranged from 1/40 to 1/4, as against 1/4500 in the case of Loch Earn. Nevertheless, for the lower nodalities the observed and calculated periods agreed within the limits of experimental error, as will be seen by the following tables:—

1. Seiches in a Concave Symmetric Complete Parabolic Lake (§ 27, H.T.S.)

N.B.—All linear measurements are in centimetres; the periods are given in seconds.

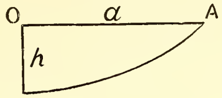


$$h(x) = h\left(1 - \frac{x^2}{a^2}\right)$$

[a = 70 cm.; h = 10·9 cm.]

h	T_1		T_2		T_3		T_4		T_5		Position of Binode $\frac{x}{a}$.	
	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.
10·9	2·98	2·99	1·72	1·73	1·24	1·22	·98	·95	·80	·77	·567	·577
9·4	2·98	2·99	1·72	1·73	...	...	...	...	...	...	·566	·577
6·2	2·98	2·99	1·72	1·73	...	...	...	...	...	...	·573	·577

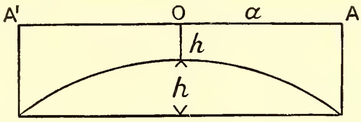
2. Seiches in a Concave Semi-Parabolic Lake (§ 34, H.T.S.)



[$a=70$ cm. ; $h=10{\cdot}9$ cm.]

h	T_1		T_2		Position of Uninode $\frac{x}{a}$.		Positions of Binodes $\frac{x}{a}$.			
	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.
10·9	1·73	1·73	·95	·95	·593	·577	·329	·340	·850	·861
9·4	1·72	1·73	·95	·95	·580	·577	·331	·340	·838	·861
6·2	1·74	1·73	·96	·95	·582	·577	·326	·340	·823	·861

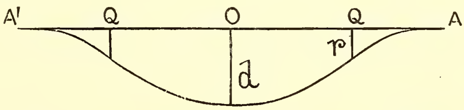
3. Seiches in a Convex Symmetric Parabolic Lake (§ 37, H.T.S.)



$$h(x)=h\left(1+\frac{x^2}{a^2}\right)$$

h	a	T_1		T_2		Position of Binode $\frac{x}{a}$.	
		obs.	calc.	obs.	calc.	obs.	calc.
2·5	35·7	2·70	2·72	1·24	1·29	·444	·472
5·4	50	2·58	2·59	1·23	1·23	·457	·472

4. Seiches in a Concave Truncated Quartic Lake (§ 52, H.T.S.)



[$p=q=OQ=\frac{1}{2}l$] $h(x)=h(a^2-x^2)^2$ [$h=\log^{-1}\bar{7}{\cdot}55594$. $d=12$]

d	l	r	T_1		T_2		T_3		T_4		T_5		T_6		T_7	
			obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.
12	70	8	1·3	1·328	·74	·688	·56	·464	...	...	...	...	...	...	...	...
12	84	5·6	1·5	1·62	·88	·85	·67	·57	·54	·43	·48	·34	·44	·29	·39	·25
12	102	3 5	2·02	2·02	1·13	1·102	·80	·748	...	...	...	...	...	...	...	...

The determination of the nodes was subject to a large experimental error, but the agreement with the theory for the lower nodalities was also as near as could be tested.

The tables for the complete and semi-parabolic lakes afford a verification of the curious theoretical result that in lakes of that form the seiche periods are independent of the rise and fall of the lake surface.

Composition of Seiches, and the Analysis of a Limnogram by Residuation

If two seiches of the same period, whose amplitudes and phases may be different, be superposed, the result is a seiche of the same

i.

ii

iii.

iv.

v.

vi.

vii.

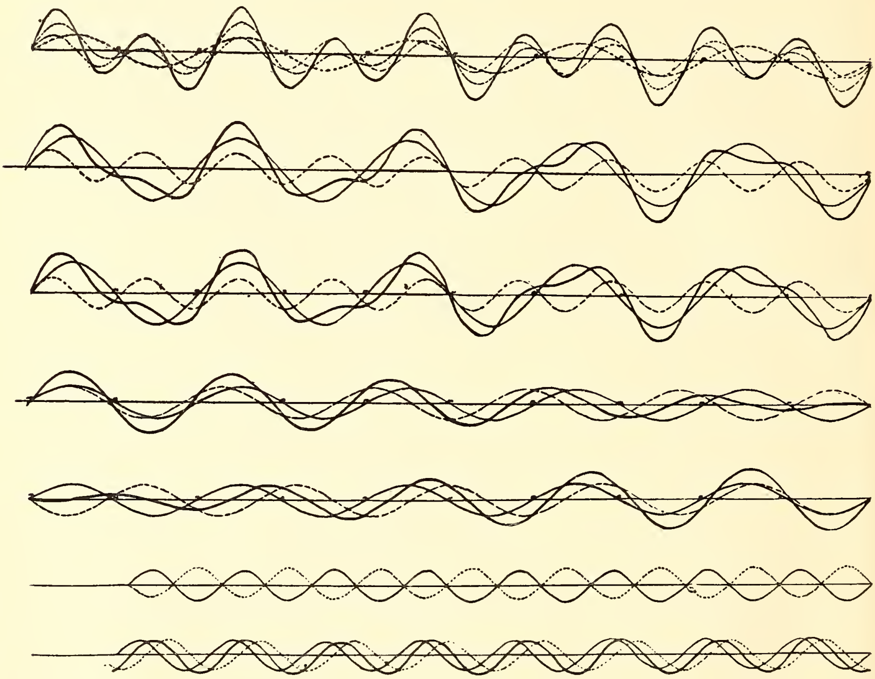


Fig. 16.

period whose amplitude and phase can be calculated, and are not in general the same as the amplitude and phase of either of the component seiches. This will be understood from the seven cases given in fig. 16, in which the thin and dotted lines represent the component seiches, and the thick line the resultant compound seiche, the ordinate of which is the algebraic sum of the ordinates of the components.

In the particular case, No. vi., where the amplitudes of the components are equal, their periods equal, and their phases differ by half a wave length, the result is that the one entirely destroys the other. In No. vii. the periods are equal, and the resultant has the same period, but a phase different from either of the components. This explains why a physical cause disturbing an existing seiche in a lake may in certain cases have the effect of altering its amplitude or its phase without affecting its period, or may destroy the existing seiche altogether.

Nos. iv. and v. show the effect of superposing two seiches of the same amplitude, but of slightly differing periods. The result is a dicrote seiche which presents to the eye the appearance of a seiche of a single definite period but of periodically varying amplitude—a phenomenon analogous to the beats caused by two musical notes which are nearly but not quite in unison.

If the periods of two components approximate to a simple

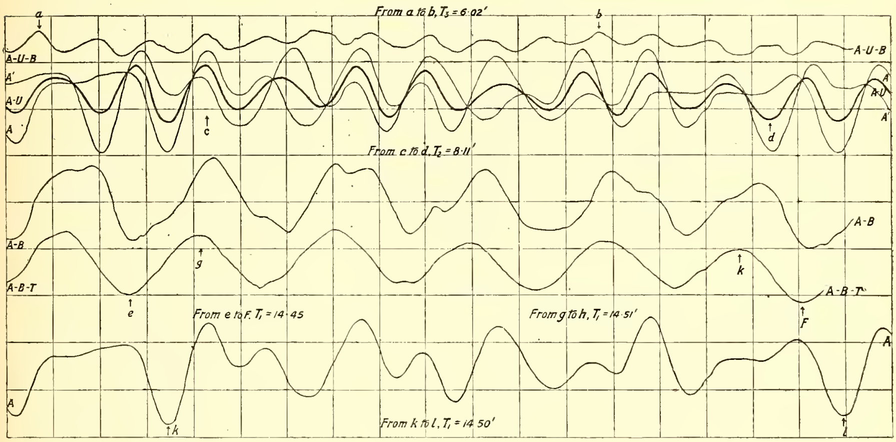


FIG. 17.

numerical proportion, say 9 : 5, as in the case of the uninodal and binodal seiches of Loch Earn, the result is a limnogram with a periodically recurring configuration like a wall-paper, the individual waves of which approximate to the waves of one of the two components if the amplitude of that component preponderates, but which fluctuates if the two amplitudes are not very different. It will be seen that the thick curves in Nos. i., ii., and iii. imitate very closely the smooth dicrote seiches reproduced in Nos. 1 and 2 of fig. 14, which were drawn one fine day near St Fillans by the unguided hand of Loch Earn.

Conversely, these principles may be used in the difficult process of analysing an actual limnogram, so as to discover the periods of the components of the seiche which it records. At the bottom of fig. 17 is reproduced part of a fine limnogram obtained by Mr James Murray from Loch Earn by a series of half-minute observations with an index limnograph, which extended over eight hours. By counting and measuring between two nearly symmetric minima, it is readily found that the longest period is about $T_1 = 14{\cdot}5$ min. On the limnogram is now superposed a tracing of itself, displaced to the left through a distance $14{\cdot}50/2 = 7{\cdot}25$, and the two curves are compounded by taking at each point half the sum of their ordinates. In the resulting curve, A–U in fig. 17, the uninodal seiche is destroyed, or at least greatly reduced. It would be destroyed altogether if the value of T_1 obtained were quite accurate. The other component seiches are altered in a known way as regards phase and amplitude, but the periods are unaltered. The result is a curve still impure, but with a well-marked period of $T_2 = 8{\cdot}11$ min. Eliminating this component as before, we get the uppermost curve, which gives a period of $T_3 = 6{\cdot}02$ min. These are good approximations to the first three periods of Loch Earn. The approximation may be refined by now residuating out (as we got into the habit of calling this process) the binodal and trinodal, and redetermining T_1 from the purified curve; then residuating out T_1 and improving the value of T_2; and so on.

This kind of analysis differs essentially from the application of Harmonic Analysis, which is quite useless—indeed, often very misleading—unless the periods are given beforehand, and only the amplitudes and phases of the components have to be determined.

Functions of the Well and Access Tube

The analysis of limnograms by the process of residuation naturally leads me to mention a method by means of which a lake may be made in some degree to analyse or purify its own limnograms.

The first purpose for which the well or closed cylinder enclosing the float of a limnograph was introduced was no doubt to shield the float from wind, breaking waves, and the meddlesome fingers of the passers-by. But it can be utilised for a further purpose. Suppose, to begin with, that the cylinder is altogether closed from the lake; then, of course, the float will not be affected by any disturbance of the lake-level. Next suppose that an access tube of very small bore is fitted. Then, owing to the smallness of the bore, the fluid friction, and the smallness of the differences of pressure at its two ends due to the denivellation of the lake, a considerable time is required before a given small denivellation runs into the cylinder enough water to produce the full effect on the float. If the outside denivellation has a long period, this is of little consequence as regards the amplitude of the motion of the float, the only marked result being that the maximum height of the float lags behind the maximum height of the outside disturbance. If, however, the period of the outside denivellation is very short, it has passed away before the flow through the access tube has had time to exert any sensible influence on the float, and the amplitude of the corresponding displacement of the recording pen is very small—it may be, quite imperceptible.

Applying the theory of fluid friction in tubes given in a classical memoir by Osborne Reynolds, it is easy to calculate the damping of the amplitude, and the lag of any pure seiche, due to a given well and tube.

If a be the diameter of the well, b the diameter, and l the length, of the access tube; and

$$\chi = 2813 b^4 / l a^2 \text{ (reduction constant)},$$

then an outside periodic disturbance

$$y = \mathrm{A} \sin nt$$

is rendered inside the cylinder by

$$x = \mathrm{A} \cos n\tau \sin n(t - \tau);$$

where τ is given by

$$\tan n\tau = n/\chi.$$

This means that there is a lag of τ seconds; and the seiche amplitude is damped in the ratio $\cos n\tau : 1$.

The two following tables show the effects of different well and access tubes on seiches of widely differing periods:—

Sarasin Limnograph at the Binode

$l = 60$ feet $= 1830$ cm., $a = 35$ cm., $b = 1\frac{1}{2}$ inches $= 3{\cdot}75$ cm. $\chi = {\cdot}2483$.

T	τ/T	τ	cos $n\tau$
sec.		sec.	
870	·00463	4·02	·9996
486	·00828	4·02	·9986
342	·01175	4·02	·9973
60	·06351	3·81	·9215

Index Limnograph with 6-inch Well, and 6 feet Tube of $\frac{1}{2}$-inch, $\frac{1}{4}$-inch, or $\frac{3}{16}$-inch Bore

$l = 182$ cm., $a = 15$ cm.

	$b = 1{\cdot}27$ cm. $\chi = {\cdot}1788$			$b = {\cdot}63$ cm. $\chi = {\cdot}01083$			$b = {\cdot}47$ cm. $\chi = {\cdot}003355$		
T	τ/T	τ	cos $n\tau$	τ/T	τ	cos $n\tau$	τ/T	τ	cos $n\tau$
sec.		sec.			sec.			sec.	
870	·0064	5·59	·9992	0937	81·5	·8320	·1808	157·3	·4213
486	·0115	5·58	·9974	·1390	67·6	·6421	·2096	101·8	·2512
342	·0163	5·57	·9948	·1569	53·7	·5078	·2213	72·5	·1797
60	·0843	5·06	·8630	·2336	14·0	·1028	·2449	14·7	·0320

By properly adjusting the relation of the access tube to the well, the limnogram may, therefore, not only be stripped of its embroidery of short-period disturbances, but to a considerable degree the prominence of seiches of higher nodality may also be reduced, and thus to some extent the lake made to do its own residuation.

Fig. 18 shows the lag and damping as seen in actual practice. The two limnograms AB and DE were taken with a 6-inch well and an access tube 6 feet long and $\frac{1}{2}$-inch diameter; but the part CD was taken with two access tubes each 6 feet long but $\frac{1}{4}$-inch diameter. The curves A to B and C to E, save for the short break at D when the tubes were changed on one of the two limnograms, were taken simultaneously at the same spot. The lag and the damping may be seen on comparing CD with the corresponding part of AB, also the greater smoothness of CD as compared with AB and DE,

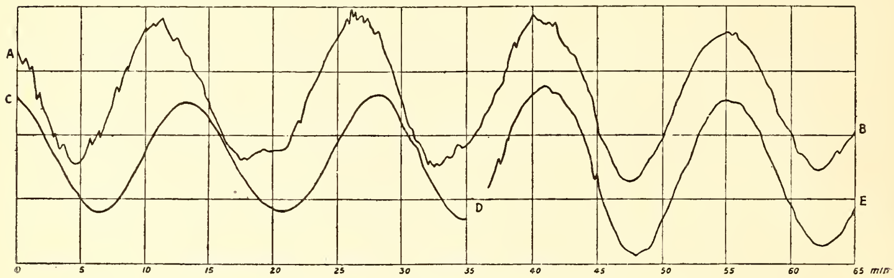


Fig. 18.

although the embroidery on these latter parts is very imperfectly rendered in these limnograms, which were plotted from eye observations.

Comparison of the Hydrodynamical Theory with Observation

The hydrodynamical theory of seiches is merely a development of the fundamental idea of Forel that a seiche is a standing oscillation of the lake as a whole, whose periods and nodes are dependent solely on the form of the lake-basin. The further this idea is carried into detail, the more of the varied seiche phenomena it is found to explain. Perhaps the best account of the present state of our knowledge of this matter will be found in the excellent review by Endrös already referred to.[1]

Before proceeding to minuter details regarding Loch Earn, the following pair of tables compiled from various sources may help the reader to appreciate the variety of seiche phenomena, and to understand the relation as to seiches between home and foreign lakes:—

[1] I ought also to refer the reader to a very thorough and highly interesting discussion by Defant of the seiches of the Lake of Garda, *Sitzber. Akad. Wiss. Wien*, Bd. cxvii., 1908, published since the above was written.

Some Foreign Lakes

Lake.	Period T_1.	Length in Miles.	Depth in Feet.	
			Max.	Mean.
Erie	960–840	250	180	...
George	131	18	...	16
Geneva	73	45	1014	500
Constance	56	41	827	295
Neuchâtel	50	24	502	210
Zürich	46	18	470	144
Lucerne	45	24	732	...
Walen	15	10	496	...
Traun	10	7	627	...
Brienz	10	9	856	...

Scottish Lakes[1]

Lake.	Periods.		$\frac{T_1}{T_2}$	Length in Miles.	Depth in Feet.	
	T_1	T_2			Max.	Mean.
Ness	31·5	15·3	2·06	24	754	433
Tay	28·4	16·4	1·73	15	508	199
Laggan	26·6	...	...	7	174	68
Lubnaig	24·4	...	...	4	146	43
Arkaig	24	...	...	12	359	153
Maree	15	...	...	13	367	125
Earn	14·5	8·1	1·79	6	287	138
Morar	14	...	...	12	1017	284
Fada	11·5	6	1·91	4	248	102
Chroisg	11·2	..	...	3	168	74
Treig	9·2	5·2	1·77	5	436	207

Periods and Nodes of Loch Earn

In order to calculate the periods and nodes of Loch Earn, twenty-nine points on its normal curve were determined from the bathymetrical data of the Scottish Lake Survey. A pair of parabolæ with a common vertex and vertical axis were then determined to fit these points as nearly as possible. This was to some extent an arbitrary process, and to avoid possible bias a particular application of the method of least squares was used to determine the parabolic constants. The nature of the fit will be seen from fig. 19. There is good general agreement between the punctuated normal curve and the biparabolic curve, but also considerable deviations in certain places. It was

[1] Except for Lochs Treig, Ness, Earn, and Tay, the determinations are very rough.

expected *a priori* that these would not greatly affect the periods, at least those of lower nodality; but it is obvious from the Hydrodynamic Theory itself that such deviations near to nodes might considerably affect their position.

To give an idea of the accuracy that is possible under the most favourable circumstances in determining the periods of a lake, I subjoin some of the tables that were used in determining the first three periods of Loch Earn. The station, the instrument, and instrumental adjustment are the same in each table, but not the same in any two tables for the same period. In the second column of each table is given the height of the surface of the lake above a certain arbitrarily fixed level. In calculating the mean from each table the

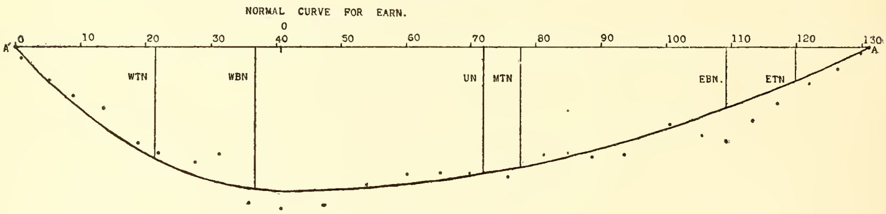


Fig. 19.

weight of each value of the period was taken to be proportional to the number of oscillations used in calculating that value.

Naturally the period most accurately determined is the uninodal. It will be seen that the mean of the results from Tables I., II., and III. is 14·524, which differs by less than ·005 from any one of the three. Probably, therefore, the determination of the uninodal period of Loch Earn differs from 14·52 by less than 1 in 1452, say ·07 per cent. The extreme accuracy of this determination of the uninodal period of Loch Earn, and incidentally also of the binodal period, is due to the great regularity and persistence of the seiches of this lake, and to the fact that the ratio T_1/T_2 is very nearly equal to 9/5; so that there is a well-marked "configuration period" in the dicrote of the uninodal and binodal seiches, which can be utilised in the determinations.

I. OBSERVATIONS WITH THE WAGGON RECORDER NEAR ST FILLANS (PICNIC POINT)

Date. 1905.		Staff. Feet.	T_1. Minutes.	Number of Oscillations.
Aug.	11	2·07	14·64	41
,,	13	1·95	14·30	19
,,	14	1·88	14·54	15
,,	14	1·88	14·60	39
,,	15	1·82	14·67	10
,,	15	1·82	14·56	46
,,	16	1·78	14·57	57
,,	17	1·72	14·47	49
,,	18	1·80	14·50	76
,,	20	2·27	14·55	65
,,	21	2·20	14 64	15
,,	22	2·30	14·57	45
,,	25	2·25	14·56	72
Sept.	2	1·90	14·58	38
,,	3	1·85	14·63	40
,,	5	1·83	14·54	71
,,	6	1·80	14·45	40
,,	17	2·80	14·49	30
,,	18	2·48	14·45	36
,,	18	2·48	14·47	66
,,	18	2·16	14·47	14
,,	18	2·16	14·55	30
,,	18	2·16	14·53	44
,,	20	2·00	14·57	27½
,,	23	1·82	14·52	24
,,	23–27	1·82–1·65	14·52	375
,,	24	1 80	14·53	79
,,	25	1·76	14·50	95
,,	26	1·70	14·53	100
,,	27	1·66	14·52	101

Weighted mean $T_1 = 14·529$.

II. OBSERVATIONS WITH THE SARASIN (AT LOW SPEED) NEAR THE E. BINODE

Date. 1905.		Staff. Feet.	T_1. Minutes.	Number of Oscillations.
Aug.	6	2·25	14·56	41
,,	7	2·25	14·47	42
,,	7	2·25	14·51	83
,,	8	2·15	14·52	75
,,	9	2·10	14·53	75
,,	20	2·30	14·62	48
,,	22	2·40	14·51	56
,,	22	2·40	14·45	74
,,	24	2·32	14·54	118
Sept.	1	2·07	14·55	30
,,	3	1·85	14·52	50
,,	4	1·87	14·53	95
,,	24	1·80	14·55	64
,,	25	1·76	14·49	106
,,	26	1·70	14·54	100
,,	23–26	1·82–1·68	14·52	270
,,	27	1·66	14·51	93

Weighted mean $T_1 = 14·524$.

III. Observations with the Sarasin (at Higher Speed) near the E. Binode

Date. 1905.		Staff. Feet.	T_1. Minutes.	Number of Oscillations.
Sept.	9	2·60	14·64	15
,,	14	2·60	14·54	10
,,	15	2·45	14·52	45
,,	16	2·30	14·53	10
,,	20	2·00	14·44	25
,,	22	1·87	14·51	50

Weighted mean $T_1 = 14·521$.

IV. Observations with the Waggon Recorder near St Fillans (Picnic Point)

Date. 1905.		Staff. Feet.	T_2. Minutes.	Number of Oscillations.
Aug.	11	2·07	8·12	74
,,	14	1·88	8·08	27
,,	14	1·88	8·13	70
,,	15	1·82	8·15	18
,,	15	1·82	8·07	83
,,	16	1·78	8·065	103
,,	17	1·72	8·055	88
,,	18	1·80	8·06	138
,,	20	2·27	8·08	117
,,	21	2·20	8·13	27
,,	22	2·30	8·10	81
Sept.	2	1·90	8·15	68
,,	3	1·85	8·12	72
,,	5	1·83	8·06	128
,,	6	1 80	8·05	72
,,	18	2·16	8·10	25
,,	18	2·16	8·08	54
,,	18	2·16	8·09	79
,,	24	1·80	8·085	142
,,	27	1·66	8·086	169

Weighted mean $T_2 = 8·086$.

V. Observations with the Waggon Recorder near St Fillans (Picnic Point)

Date. 1905.		Staff. Feet.	T_3. Minutes.	Number of Oscillations.
Aug.	12	2·07	6·14	36
,,	13	1·95	5·89	29
,,	21	2·20	5·91	45
,,	29	2·22	5·98	36
,,	29	2·22	6·01	48
,,	30	2 15	6·07	65
,,	31	2·10	6·00	60
Sept.	3	1·85	5·98	36
,,	23	1·82	6·008	58

Weighted mean $T_3 = 6·005$.

In Table VI. are entered side by side the values of the various periods deduced from the whole series of observations, the values (up to T_6) deduced from the Hydrodynamical Theory, and the values deduced from the formula of Du Boys. It will be remembered that this last formula agrees better and better with the Hydrodynamical Theory as the nodality rises, and finally gives the same result.

VI. Comparison of Calculation with Observation

ν	T_ν by H.T.S.	T_ν by Du Boys.	T_ν observed.
1	14·50	17·81	14·52
2	8·14	8·91	8·09
3	5·74	5·94	6·01
4	4·28	4·45	3·99
5	3·62	3·56	3·48–3·60
6	2·93	2·97	2·88
7	...	2·55	...
8	...	2·23	...
9	...	1·98	...
10	...	1·78	1·70 ?
11	...	1·62	...
12	...	1·48	1·54 ?
13	...	1·37	1·36 ?
14	...	1·27	1·31 ?
15	...	1·19	1·15 ?
16	...	1·11	1·09 ?
17	...	1·05	...

The identification of the quadrinodal and quinquinodal periods respectively rests merely on the comparatively close agreement of certain observed numbers with each other and with the quadrinodal and quinquinodal periods deduced from the Hydrodynamical Theory and from Du Boys' formula. No phase observations were available to assist the identification.

There is still greater uncertainty regarding the higher periods, most of which rest only on a single series of oscillations. Possibly $T = 2·88$ is the sextinodal period. It must, however, be borne in mind that the smaller the period, the greater is the danger of confusion with progressive wave disturbances, with possible transversal seiches, or even with secondary local oscillations due to indentures in the shore of the lake.

During the observations the mean level of Loch Earn varied through a range of nearly 20 inches (over 50 centimetres), but a careful examination of the tables of values of the periods under different circumstances does not appear to show any correlation between the depth of the lake and the various periods. It follows that in the case of Loch Earn, within the range of the observations, the periods are independent of the depth.

From the theoretical point of view, there is nothing surprising in the result just arrived at. Let us consider elongated lakes of uniform breadth, and assume that the same normal curve continues to represent the lake-basin when the mean level rises or falls. For a lake whose longitudinal section is a rectangle $T_\nu = 2l/\nu \sqrt{(gh)}$. Hence, since in this case l is constant, as h increases all the periods diminish. If the longitudinal section is parabolic, then $T_\nu = \pi l / \sqrt{\{\nu(\nu+1)gh\}}$.[1] In this case l is proportional to $\sqrt{h}$; hence all the periods are independent of the depth of the lake. It is easy to see from the analysis in H.T.S., p. 628, that the same is true for a biparabolic lake. If the longitudinal section be rectilinear and symmetrical, shelving at both ends, then $T_\nu = 2\pi l / j_\nu \sqrt{(gh)}$.[2] In this case l is proportional to h, and j_ν is a mere number depending only on the nodality; hence T_ν is proportional to $\sqrt{h}$—that is to say, all the periods increase when h increases. Generally speaking, we may expect the rise of the mean level in a lake to increase its periods if the rise greatly increases the horizontal surface of the lake; and to decrease the periods, if the rise increases the horizontal surface very little. It appears from the observations of Forel[3] and Ebert[4] that the Lake of Geneva and the Starnberger See belong to the latter category; and Halbfass[5] has found that the Madüsee belongs to the former. Loch Earn occupies an intermediate position; the constancy of its periods is therefore an indication that the assumption of a biparabolic normal curve is a good first approximation.

The calculated positions of the nodal lines of Loch Earn are shown by red lines on the map which accompanies the paper C.P.N.

The difficulties anticipated[6] in determining the nodes by direct observation were more than realised in practice. When the range of the seiche is large, there is nearly always a great deal of wind-embroidery of an irregular character, which it is impossible to eliminate entirely either by damping the limnograph or by residuating the limnogram. Also, where the amplitude is small, there is almost always sensible disturbance arising from an aperiodic variation of the lake level, probably due to the heaping up of the water on the shallow shore, an effect which will vary with the slope of the beach. The varying slope also affects the range of the seiche at the margin of the lake to an extent which it would be difficult to calculate

[1] H.T.S., p. 622.

[2] H.T.S., p. 638.

[3] *Le Léman*, t. ii. p. 122.

[4] "Periodische Seespiegelschwankungen beobachtet am Starnberger See," *Sitzber. kgl. bayer. Akad. Wiss.*, Bd. xxx. p. 453, 1900.

[5] "Stehende Seespiegelschwankungen im Madüsee in Pommern," *Zeitschr. f. Gewässerkunde*, Bd. vi. p. 65, 1902.

[6] C.P.N., p. 850.

with any degree of accuracy. Both these causes introduce uncertainty in the method of observing with index limnographs on two sides of the node where the seiche is found in opposite phases, and then deducing its position by interpolation. A mere null method would scarcely lead to a satisfactory result, unless under exceptional circumstances which did not occur during the observations. Of the many attempts made, only a few led to limnograms which could be utilised; and in every case the curves had to be purified by residuation.

Uninode.—The two best pairs of observations gave almost exactly the same position for the southern end of the uninode, and led to the conclusion that it lies about 105 yards west of the position given in the paper on the Calculation of the Periods and Nodes of Lochs Earn and Treig. This is precisely what was expected, as the actual normal curve (C.P.N., p. 825) rises above the assumed biparabolic curve on the west and falls below it on the east of the calculated position of the uninode. It would be useless to calculate what the amount of divergence ought to be, because the uncertainty of one of these determinations, as shown by the observations themselves, is ±65 yards, and of the other ±129 yards, the latter being more than the divergence itself. The exact agreement of the two determinations is probably an accident.

Eastern Binode.—Two determinations agreed almost exactly in placing the Eastern Binode about 117 yards west of the calculated position; but the uncertainty of these determinations was ±94 yards in the one case and ±59 yards in the other.

Western Binode.—The best pair of observations gave a position for the southern end of the Western Binodal line 305 yards west of the calculated position. A divergence in this direction was to be expected from the shape of the true normal curve in the neighbourhood, but the amount is somewhat surprising. There can be little doubt of the correctness of the observation, because it was confirmed by another pair of observations, one made almost exactly at the position above indicated, the other 250 yards farther east. The latter gave on residuation a well-marked binodal seiche, the former none that could be recognised.

Eastern Trinode.—The best observation available places the southern end of the Eastern Trinodal line 88 yards west of the calculated position. The uncertainty of the determination, however, exceeds 120 yards, so that it cannot be said for certain whether the actual trinode is really west or east of the calculated position; from the shape of the normal curve we should expect a considerable divergence to the east.

Middle Trinode.—Unfortunately the observations for the determination of the Middle Trinode were rendered useless by casual wind-disturbances.

Western Trinode.—No observations of sufficient accuracy were available.

Effect of Meteorological Conditions upon the Denivellation of Lakes

General Character of the Seiches on Loch Earn.—Owing to the comparatively regular shape of its basin, and the fact that the depth is considerable compared with the length, the seiches on Loch Earn are very regular and very persistent. Also, probably because its longest axis is more or less parallel to the paths of the major and minor atmospheric disturbances,[1] Loch Earn is very rarely free from seiches. During 1070 hours, from 10th August to 28th September, the waggon recorder at Picnic Point was almost constantly in action; yet only 2½ hours of calm[2] were recorded. During 1350 hours, from 12th October to 7th December, while the waggon recorder was in action at Lochearnhead, there were in all about 90 hours of calm. Of these, 81 hours were made up by continuous stretches of 21^h, 37^h, and 23^h on 4th, 16th, and 20th November.

The greatest ranges observed in August and September were 79 mm., 66 mm., 73 mm., 55 mm., 55 mm., 63 mm., on 19th and 21st August and 3rd, 7th, 8th, and 9th September respectively. Only one very exceptional range was observed between 12th October and 7th December, viz. 55 mm. on 7th December.

The range of the seiche at St Fillans is usually over 10 mm. A rough estimate showed that during the 1070 hours of observation at Picnic Point the range of the seiche was over 30 mm. during 214 hours; and during the 1350 hours at Lochearnhead it was over 30 mm. during 57 hours only. It follows that, whether we test by hours of calm, by hours of excess over 30 mm., or by occurrence of exceptional ranges, the period from 12th October to 7th December showed much less seiche activity than the period from 10th August to 28th September.

In more or less settled weather, by far the commonest seiche configuration on Loch Earn is a uninodal and binodal dicrote.[3] This varies between the two extremes where the binodal on the one

[1] See my paper, "On the Theory of the Leaking Microbarograph, etc.," *Proc. R.S.E.*, vol. xxxviii. p. 454, 1908.

[2] *I.e.* whole range of seiche less than 2 mm.

[3] For brevity, in what follows such a seiche will be denoted by "UB-dicrote." Similarly, "UBT-tricrote" would mean a tricrote seiche with uninodal, binodal, and trinodal components, and occasionally the amplitudes (half ranges) of these components will be denoted by U, B, T, respectively.

hand and the uninodal on the other are scarcely noticeable, but the seiche in our observations was hardly ever either purely uninodal or purely binodal. In these seiches the 5–9– configuration period caused by the interference of the uninodal and binodal components is usually reproduced with the most beautiful regularity, sometimes for a whole day or even longer. For example, in the seiche observed at Lochearnhead from 16th to 22nd October 1905, which lasted about $6\frac{1}{2}$ days, say for 127 configuration periods, only six of these periods were found too short by one uninodal, and three too long by the same amount. It is probable that the gradual change of phase ac-

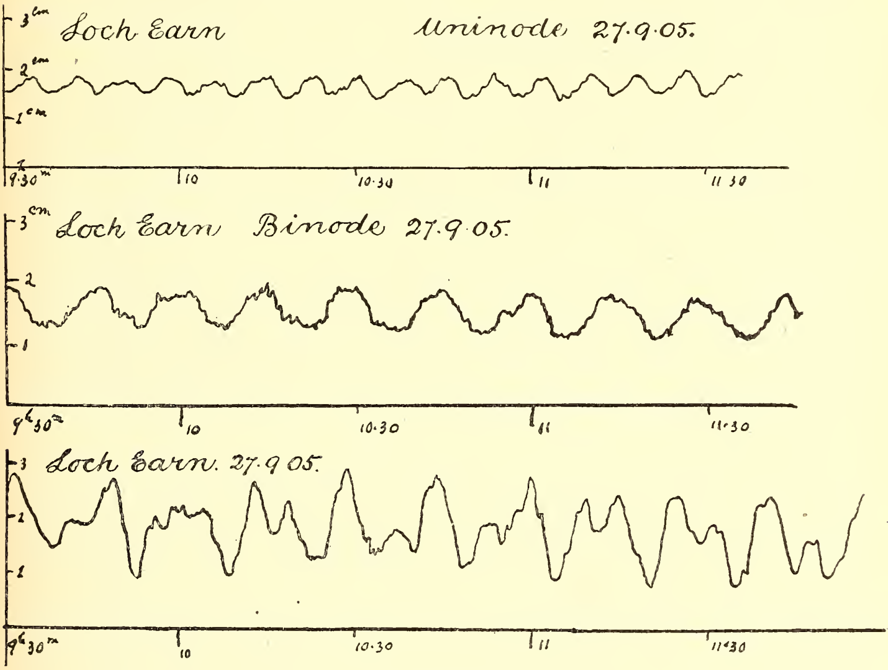


Fig. 20.

companying the rise and fall of the amplitudes of the components more than compensated for the fact that 9/5 is not so close an approximation to T_1/T_2 as is the sixth convergent, 70/39.

In times of storm, or even moderate wind, there is, of course, a strong embroidery of various kinds, but usually the UB-dicrote configuration can be seen through all the confusion, and it soon becomes the prominent feature when the weather begins to settle.

At this point we may indicate how the lake can be made to analyse its own seiches. Fig. 20 shows three simultaneous limnograms, the lowest one taken at Picnic Point, about 480 yards from the eastern end of the lake, the middle one taken near the binode, the uppermost one taken near the uninode. All three are somewhat embroidered by the wind, but the St Fillans seiche is a UB-dicrote, the middle one a nearly pure uninodal, and the uppermost one a nearly pure binodal. The figure is at once an interesting confirmation of Forel's theory, and a verification of the approximate accuracy of the mathematical theory of Loch Earn regarded as a biparabolic lake.

Comparison of Loch Earn with Lochs Tay and Lubnaig

The seiches of Loch Tay present the strongest possible contrast to the seiches of Loch Earn. No clear dicrote or other easily recognisable

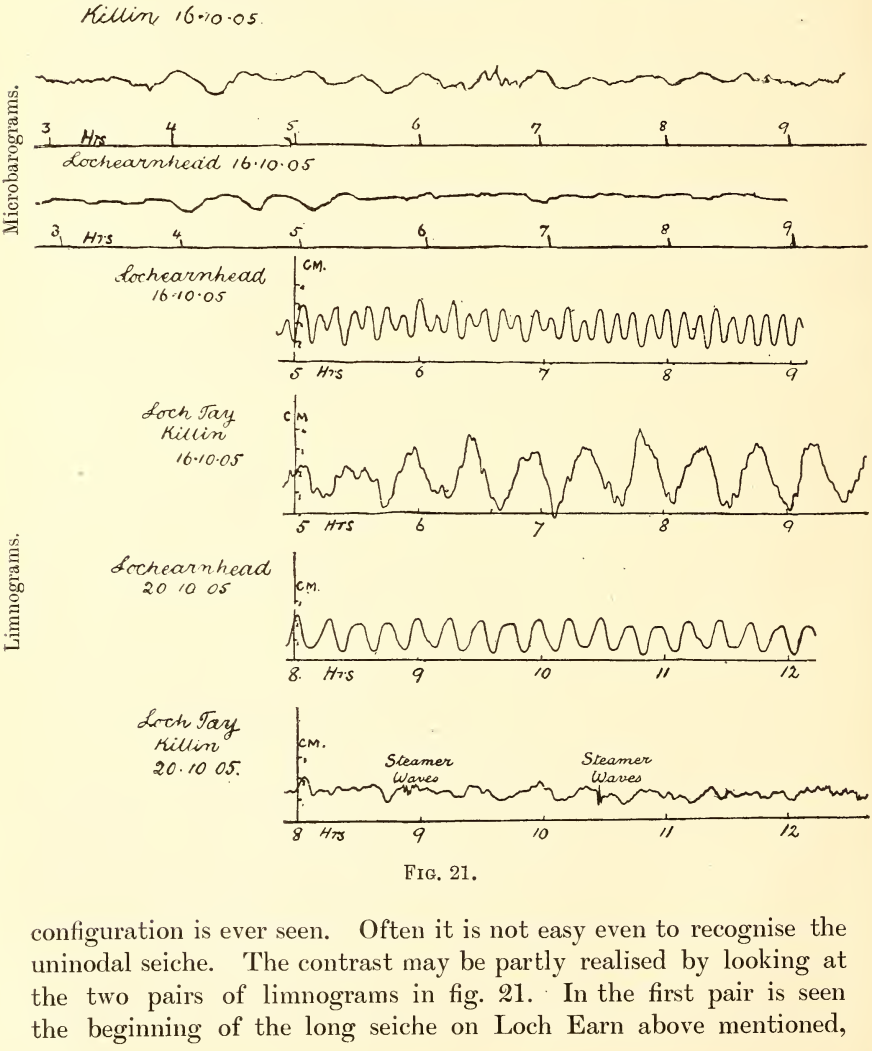


Fig. 21.

configuration is ever seen. Often it is not easy even to recognise the uninodal seiche. The contrast may be partly realised by looking at the two pairs of limnograms in fig. 21. In the first pair is seen the beginning of the long seiche on Loch Earn above mentioned, alongside of the simultaneous seiche on Loch Tay—which was the most regular one found on that lake between 4th October and 9th November 1905. The second pair is the end of the long seiche on Loch Earn with the simultaneous one on Loch Tay, whose irregularity is typical.

As yet our knowledge of the seiches and meteorological conditions of Loch Tay is not sufficient to enable us to explain this difference, but it may be pointed out here that Loch Tay is relatively a shallower lake than Loch Earn, it is more crooked, and the relation of its axial line to the path of the minor atmospheric disturbances is different.

This divergence of conditions occurs in an exaggerated form in the case of Loch Lubnaig, which is very shallow, has a very irregular basin, and lies across the path of the atmospheric disturbances. Accordingly, only four cases were found in which a definite seiche could be recognised in Loch Lubnaig, having a period of about 24 min., and in each case only a few undulations could be counted. One of these seiches is shown in fig. 22. During the rest of the six

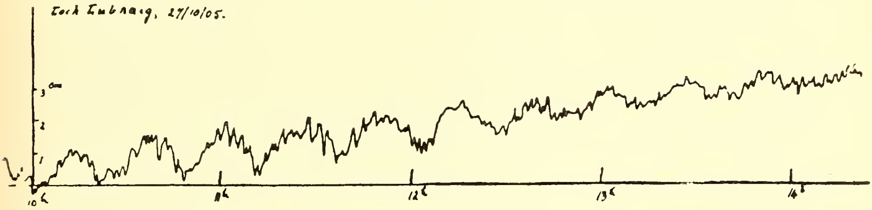


Fig. 22.

weeks of observations nothing was found but wind embroidery and sub-permanent wind denivellation, such as would be naturally expected in a shallow lake. About this negative result there seems to be little room for doubt, as the indications of the converted Sarasin limnograph were controlled by occasional observations with the much more delicate index limnograph.

For our disappointment in Lochs Tay and Lubnaig we find consolation in the beautiful seiche behaviour of Loch Earn, which we regard as a small but elegant daughter of the Lake of Geneva, the great mother of seiches.

Origin of Seiches

Forel and his followers, Du Boys, Von Cholnoky, and others, have discussed the causes of seiches; and recently Endrös, in his important memoir on the Chiemsee, has confirmed the conclusions of his predecessors, and added some fresh details of great interest. In what follows we shall not advance anything of great novelty, but there are two points of interest that may be worthy of the reader's notice. In the first place, the use of the Dines-Shaw microbarograph enabled us during our observations on Loch Earn to follow continuously the minute variations of the atmospheric pressure with an ease and certainty hitherto unattainable.[1] Also, in Part V. of my "Report on the Investigation of the Seiches of Loch Earn by the Scottish Lake Survey," the mathematical theory of the effect of pressure disturbances of various kinds on an ideal lake, of form not very remote from Loch Earn, has been worked out,[2] so as to show that the usually assigned cause of seiches, viz. the minor local fluctuations of the barometric pressure, is in reality sufficient to cause the disturbances observed, and is not a negligible quantity on ordinary lakes, such as the tidal action of the moon can be shown to be.[3]

Regarding those causes of seiches which have never yet been proved to be other than accidental, it may be of interest to record the fact that during our observations, viz. on 21st September 1905, at 23^h 33^m, we were favoured with what Dr C. Davison,[4] in a paper on the Ochil earthquakes, calls a "principal earthquake." The estimated duration of the shock was 3·4 sec. Some of the members of my family who heard it, took it for the rumble of a train passing at an unusual hour on the opposite side of Loch Earn. The centre of disturbance seems to have been about 19 miles S. 39° E. of St Fillans, and the normal to Dr Davison's isoseismal 4 makes an angle of about 63° with the axis of Loch Earn. At the moment the waggon recorder was not working, but the converted Sarasin at the binode was running at high speed (158 mm. per hour) and giving a smooth trace. The circumstances were as favourable as could be conceived for showing any seiche disturbance due to the earthquake, but none can be identified. There is, of course, no reason to expect that the rapid oscillations of ordinary earthquakes could cause seiches. Still, negative evidence in special cases is not without value, because in exceptional cases, such as the Lisbon earthquake of 1755, seiches have been produced, and we do not as yet know the reason why.

Observers are now agreed that the development of seiches usually accompanies local disturbances of the barometric pressure whose duration if they are transitory, or period if they are periodic, does not differ greatly from the period of the seiche in question. The observations on Loch Earn fully bear out this conclusion. Disturbance on the microbarogram is always accompanied by disturbance on the limnogram, although the magnitudes do not always correspond.

[1] A separate account of the observations with the microbarographs has been published in the *Proc. Roy. Soc. Edin.*, vol. xxviii. p. 437, 1908.

[2] *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 499, 1908.

[3] Except in very large lakes, such as Erie. See Endrös, *Petermann's Mitt.*, Heft ii. p. 16, 1908.

[4] *Quart. Journ. Geol. Soc.*, vol. lxiii. p. 366, 1907.

Sometimes a violent disturbance on the microbarogram is accompanied by a moderate or slight disturbance on the limnogram, and occasionally the disturbance on the limnogram is much greater than might at first sight be expected from the microbaric disturbance. The mathematical theory (and indeed common sense apart from recondite theory) indicates the reason for this. If an increase of pressure operates on one half of a symmetric parabolic lake during half the period of the uninodal seiche while the water in that half is falling, it will evidently work the whole time towards increasing the amplitude of the seiche. Also, if there were to be increase of pressure for half-periods alternately on the two sides of the uninode, always tending to drive the water in the direction in which it was going, it is obvious that a very small increase might end by producing a very large seiche. As a matter of fact, a considerable rise of seiche is occasionally found when the microbarogram is comparatively smooth, but in such cases a closer examination usually shows a faint undulation with a period not very different from that of the seiche which is generated.

On the other hand, if an increase of pressure is supposed to act on one half of the parabolic lake during the whole period of the uninodal seiche, or if it is distributed equally on both sides of the uninode, it is easy to see that the final result in altering the range of the seiche will be nil, however long the increase of pressure may act.

Absence of microbaric disturbance is accompanied by absence of seiche disturbance; that is to say, either there is no seiche at all, or an existing seiche continues unaltered. Under these circumstances the limnograms from Loch Earn are of great beauty. As an example, mention may be made of a record taken by the converted Sarasin near the binode from 23rd to 27th August. This shows a regular uninodal seiche with an average range of 6 to 7 mm., which continued for over eighty-nine hours. During all that time the microbarogram shows only very slight disturbance—faint undulations, occasionally periodic. The range of the seiche is not absolutely constant, but sometimes rises and sometimes falls gradually, the minimum being, say, 4·5 mm. and the maximum 8 mm. (corresponding to 7 mm. and 13·6 mm. at St Fillans). There is nowhere any sudden change of phase.

Examination of the limnograms shows that seiches may be generated "suddenly," *i.e.* attain their full range in one or two oscillations, or may be generated "gradually," *i.e.* the full range may be attained only after a considerable number of oscillations.

Among the causes that might generate seiches suddenly the following may be considered:—

1. The sudden release of a static denivellation of the whole lake-surface, due to the progression of the general system of the atmospheric isobars.

2. Sudden release of a denivellation, caused by the transport of water from one end of the lake to the other by a wind which has blown in one direction for a time and then fallen calm or reversed its direction.

3. A sudden denivellation in one part of the lake due to very rapid flooding.

4. A sudden denivellation due to a heavy fall of rain, snow, or hail over a part of the lake. This might be partly static, *i.e.* due merely to the gravitation of the precipitated water; or it might be partly dynamic, *i.e.* due the impact of the precipitated water.

5. Sudden alteration of the atmospheric pressure, due to the passage over parts of the lake of a local atmospheric disturbance (squall), such as is indicated by a disturbance on the microbarogram.

6. The impacts of wind-gusts on the lake-surface.

Among causes that might be expected to generate seiches gradually may be mentioned :—

7. The action over portions of the lake-surface of small fluctuations of the barometric pressure which happen to synchronise more or less nearly with some of the seiche periods of the lake.

8. Action similar to last of fluctuation in the velocity and pressure of the wind, as shown in the anemogram.

1. **Effect of the Progression of the General System of the Isobars.**—In order to form an idea of the potency of cause 1, let us take an extreme case. The greatest gradient noticed on the weather charts for August and September 1905 was 2·5 mm. of mercury, *i.e.* 34 mm. of water, in about 30 sea miles. Taking the length of Loch Earn as 6 miles, this would give a difference of pressure between the two ends of 6·8 mm. of water. At a distance of about 50 miles on the chart the gradient had fallen by about one-fifth. Taking an extreme supposition, viz. that the system of isobars travelled with a velocity of 30 (mile/hour) in the direction of the maximum gradient, which is further assumed to be in the axis of Loch Earn, then the decrease of pressure difference in an hour would be $6{\cdot}8 \times 3/25$. A variation of this kind (supposing the gradient uniform over Loch Earn) can only generate the uninodal of Loch Earn, the period of which may be taken roughly to be 15^{m}. If the time of action be now supposed to be the most favourable, viz. $7\frac{1}{2}^{m}$, and the increase of the gradient to be uniform in time, then, by the mathematical theory above referred to,[1] the increment in the range of the uninodal seiche is

$$6{\cdot}8 \times 3/25 \times 16 = {\cdot}051 \text{ mm.}$$

An alteration of this amount would, of course, be invisible on the limnograms. It seems hopeless, therefore, to look for an explanation

[1] *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 513, 1908.

of ordinary seiches in the variations of the general system of isobars shown in the daily weather charts.

2. **Effect of Wind Denivellation.**—It is well established by the researches of Sir John Murray that a wind which has prevailed for some time causes transport of the water of a lake in the direction in which the wind is blowing, and the observations of von Cholnoky on Lake Balaton show that in shallow lakes this wind denivellation may be considerable, and that its sudden release may give rise to seiches.

After a long and careful examination of our limnograms, we have arrived at the conclusion that this kind of denivellation is very small on Loch Earn under ordinary circumstances, and is rarely an effective cause of seiches. It is, however, not easy to judge of this matter. When the wind is light, the effect is very small, and cannot be separated from the denivellations due to precipitation and evaporation, and to variations in the barometric gradient. When the wind is high it is usually accompanied by considerable fluctuations of the barometric pressure, or by rainfall, or by both; and again the difficulty of separating the causes arises. That wind denivellation should be small on Loch Earn is not surprising, for, looking at the ratio of its depth to its length, we must classify it as a deep lake, and in such lakes, as is now well known, the return under-current readily forms, and prevents the accumulation of wind denivellation.

The seiche of 3rd September 1905 (fig. 23) is interesting in the present connection, and also because it was accompanied by the strongest gale experienced during the two months of observation.

For some hours before midnight the wind had been very light, and at 2^h it was practically calm. About $2^h\ 37^m$ the wind began to rise, and in an hour it had reached a mean velocity of about 15 (mile/hour). The velocity fluctuated between 6 and 15 till 7^h, when a very sudden rise began. By $7^h\ 30^m$ the average velocity had risen to 35, with extremes of 45 to 50. About $8^h\ 30^m$ there was a sudden drop to about 25, then a more gradual drop to 10 at $9^h\ 20^m$. After that the gale rose again to a mean velocity of 35 to 40, with extremes occasionally reaching 53. After lasting four hours, the gale began to abate about 15^h, and then fell more or less uniformly to calm about 20^h, there being two rather sudden lulls at 17^h and $19^h\ 20^m$.

Throughout the whole of this time the microbarogram is much disturbed. During the strongest parts of the gale it shows the characteristic wind blurring, and throughout there are fluctuations of various periods: *e.g.* 7·2′ at 2^h, 5·6′ at $4^h\ 30^m$, 13·6′ at $8^h\ 30^m$, 17′ at 16^h.

Till about midnight there had been a fairly regular UB-seiche with a small trinodal component, the total range of the whole being about 31 mm. Soon after midnight, that is, more than two and a

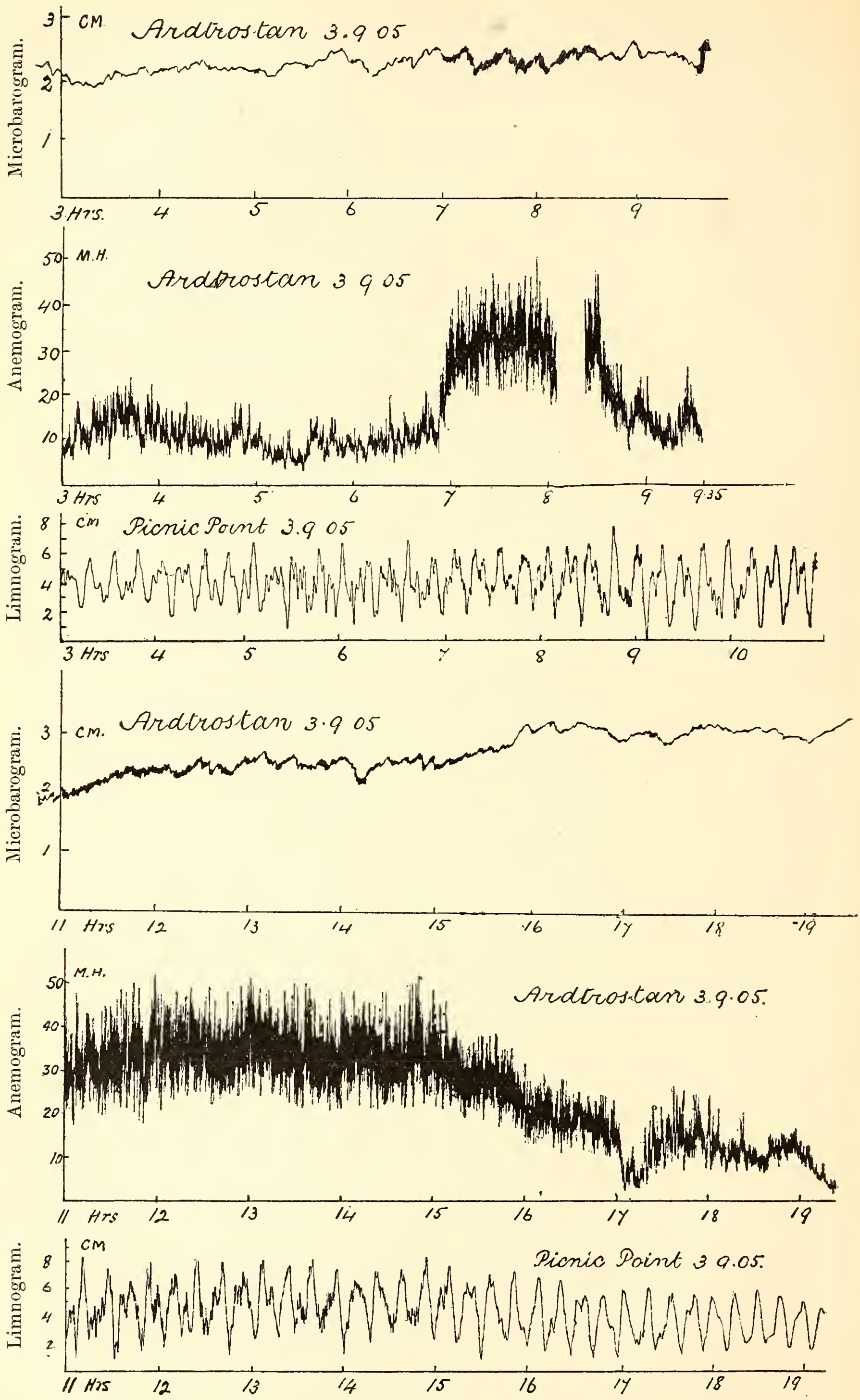

Microbarogram.
CM.
Ardrostan 3.9 05
3 Hrs.
Anemogram.
M.H.
Ardrostan 3 9 05
3 Hrs
9.35
Limnogram.
cm
Picnic Point 3.9 05
3 Hrs
Microbarogram.
cm.
Ardrostan 3·9 05
11 Hrs
Anemogram.
M.H.
Ardrostan 3.9.05.
11 Hrs
Limnogram.
CM
Picnic Point 3 9.05.
11 Hrs

Fig. 23.

half hours before the wind began to rise, the limnogram begins to show serious disturbance. This disturbance becomes strongly marked at 5^h, when the total range of the seiche reaches 60 mm., and there is a strong development of seiches of higher nodality, in particular of one having a period of about $2{\cdot}9^m$.

At 7^h, when the wind suddenly rises into a gale, there is no very marked change in the seiche. But between $8^h\ 30^m$ and 9^h there is an increase in the total range from 56 mm. to 78 mm., due no doubt to the simultaneous microbaric disturbance, which has a period of about $13{\cdot}6^m$. After this the seiche tends to settle down into a UB-dicrote, strongly embroidered with higher components while the gale lasts. It is worthy of note that at 14^h, *i.e.* seven hours after the gale commenced, the mean level of the lake at Picnic Point near St Fillans has only risen about 6 mm. About 16^h there is a decrease in the total range of the seiche from 64 mm. to 51 mm. This may be due partly to the drop in the wind, but much more probably to the simultaneous microbaric disturbance, which has a period of about 17^m, and would strongly affect the uninodal component of the seiche.

The range of the disturbance on the microbarogram was a little under 2 mm., and the data from the triangle of microbarographs showed that it travelled along the lake with a velocity of 53 miles an hour. For rough purposes and for convenient calculation we may take 48 instead of 53, and suppose the period of the pressure disturbance and also the uninodal period to be 15^m, and the circumstances as to phase to be the most favourable possible. The mathematical theory[1] then gives 3 mm. for the addition to the amplitude of the uninodal in 15^m. The effect after two undulations will therefore be 6 mm., that is, an alteration of 12 mm. in the range of the seiche, which, as it happens, is within a millimetre of the value observed.

3. **Case in which a Seiche was probably caused by a Flood.**—Fig. 24 shows the limnogram, taken near the binode, of a seiche disturbance beginning at $16^h\ 9{\cdot}6^m$ on 4th August 1905. The upward slope is due to a sudden rise in the lake caused by heavy rain. On the 3rd there had been ·96 inch of rain, and on the 4th 2·03 inches, the greatest rainfall observed during August and September. The limnograms taken at the uninode and Picnic Point are similar, except that the former shows merely a feeble binodal seiche, while the latter has a well-marked trinodal superposed on the uninodal seiche.

The wind on the 4th was light and easterly, but a well-marked barometric depression, travelling with a velocity of about 18 (mile/hour), passed in a direction towards N. 15° E., probably a little to the west of Loch Earn, the centre being nearest about $0^h\ 52^m$ on the 5th.

[1] *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 516, 1908.

The microbarograph at Ardtrostan shows a somewhat gradual drop of 2 mm., followed by a sharp rise of 4 mm. between $15^h\ 44^m$ and $16^h\ 3^m$.

It does not appear that either the passage of the main depression, or the minor fluctuation attending it, could have caused the sudden

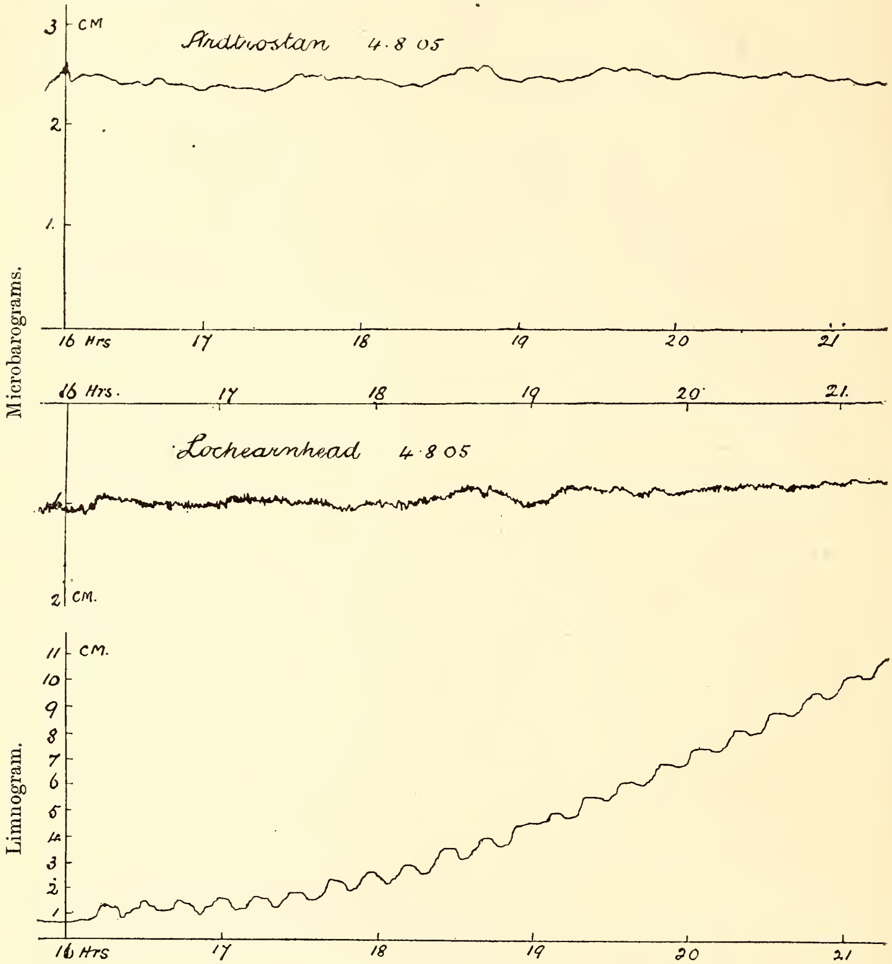


Fig. 24.

initial rise shown on the limnogram at $16^h\ 9{\cdot}6^m$. Both of these causes would indeed have worked, if at all, in the opposite direction.

We are therefore driven to the probable conclusion that the uninodal seiche was caused by the flood. A glance at a map of the neighbourhood shows that the area—Glen Beich, Glen Ogle, Glen Droma, Glen Ample, and Glen Voirlich — which drains into the western half of Loch Earn much exceeds that—Glen Tarken, Allt an

Fionn, and Finglen—which drains into the eastern half. It appears from the limnogram that for some time after the flood commenced the level of the whole lake was rising at the rate of ·32 mm. per minute. In half the period of the uninodal seiche this would give a rise of 2·3 mm. Supposing this flood at the very beginning to be thrown only on the western half of the lake, there would be a disturbance equivalent to an increase of atmospheric pressure of 4·6 mm. of water. Acting during half the uninodal period, this, by the mathematical theory,[1] would produce uninodal and trinodal seiches having extreme amplitudes of 6·8 mm. and 2·8 mm. If the first incidence of the flood were concentrated on, say, the western quarter of the lake-surface, the resultant seiche would, of course, be still greater. The rise shown at the binode was actually about 5·5 mm., which corresponds to an extreme amplitude for the uninodal seiche of 9·4 mm. It is therefore quite possible that the seiche may have been wholly due to the sudden flood on the western half of Loch Earn, and there appears to be no other way of accounting for it.

4. **Effect of Rainfall.**—In order to obtain an idea of the effect of heavy rainfall in causing a seiche, suppose a cloudburst to fall on the eastern half of Loch Earn (idealised into a symmetric parabolic lake). If σ denote the rainfall in centimetres per second, v the velocity of the rain-drops as they reach the surface of the lake, p the pressure at time t after the shower begins, then

$$\begin{aligned} p &= \sigma(v + gt) \quad (\text{dyne/cm.}^2) \\ &= \sigma v/g + \sigma t \quad (\text{gm./cm.}^2)\,; \end{aligned}$$

or, if the pressure be measured in millimetres of water,

$$\begin{aligned} p &= 10\sigma v/g + 10\sigma t \\ &= q + rt, \quad \text{say.} \end{aligned}$$

Suppose that the shower begins when the uninodal seiche culminates, and that it lasts for half the uninodal period. Then, if ∂k_1 denote the alteration in the amplitude of the uninodal seiche at the end of the lake, by the mathematical theory [2]

$$\partial k_1 = \tfrac{3}{2}q + \tfrac{3}{4}r\mathrm{T}_1,$$

where $\frac{3}{2}q$ is due to the impact, and $\frac{3}{4}r\mathrm{T}_1$ to the static effect of the precipitated water.

To take an extreme case,[3] let $\sigma = {\cdot}2/60 = {\cdot}1/30$, $v = 700$. Then, taking $\mathrm{T}_1 = 15 \times 60$ as a round number, $q = {\cdot}024$, $r = 1/30$. Hence

$$\partial k_1 = {\cdot}036 + 22{\cdot}5 = 23 \text{ mm., say.}$$

[1] *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 503.

[2] *Ibid.*, p. 512.

[3] See Hann, *Lehrbuch der Meteorologie* (1906), pp. 270, 275.

The result would therefore be a seiche having a range of 46 mm. It will be noticed that the effect arising from the impact, viz. ·036, is negligible.

The conclusion thus arrived at bears out the inference of Endrös[1] regarding the effect of a rainfall of 7 mm. during 20^m upon the 43^m seiche of the Chiemsee. Such a fall on one half of a parabolic lake having a 40^m period would generate a uninodal seiche having a range of 10·5 mm.

There is little doubt that in some of the cases, to be cited presently, the precipitation played an important part; but the observations of Shaw and Dines on the effect of passing rain-clouds in raising the barometric pressure tend to place difficulties in the way of separating the effect of precipitation from the barometric pressure proper. It would appear that the pressure to which the lake reacts so delicately is equal to the pressure before the rain has fallen—that is, while it is still in the cloud in the form of vapour; but the matter requires and deserves further investigation.

5. **Effect of Squalls.**—On 11th August, 8^h to 9^h, a prolonged depression on the microbarogram is associated with a prolonged elevation on the limnogram. The release of this denivellation caused a considerable uninodal seiche (see fig. 25).

On 7th September, about 8^h 30^m, occurred the greatest barometric fluctuation of short duration observed.[2] The extreme range was 19·3 mm. (Aq.), the total duration about half an hour. It came from E. 56° N. with a velocity of propagation of 19 (mile/hour), the velocity along the lake being about 30.

As will be seen from fig. 26, the effect was to increase the total range of the seiche from about 18 mm. to 50 mm., and to generate a strong BT-dicrote. It is worthy of remark that the rise in the wind follows about an hour after the barometric disturbance. To the spiky anemogram which then follows corresponds a strongly embroidered seiche, which shows no increase in maximum range. I have tried, but unsuccessfully, to find a period in the anemogram corresponding to that of the seiche-embroidery, viz. $T = 1{\cdot}5^m$ to $1{\cdot}6^m$.

On 8th September, between 16^h and 17^h, a well-marked barometric disturbance, having a range of 3 mm. to 4 mm. (Aq.), caused a change of phase in the previously existing UB-seiche, and also a considerable increase of range. This UB then persisted for nearly 24^h, until about 13^h 15^m on the 9th September its configuration was utterly destroyed by the great barometric disturbance shown in fig. 27. This disturbance lasted nearly two hours, and caused a maximum depression of 14 mm. (Aq.); it came from W. 62° S. to W. 67° S., and travelled

[1] *Seeschwankungen beobachtet am Chiemsee* (1903), p. 103.

[2] For further details see my paper, *Proc. Roy. Soc. Edin.*, vol. xxviii. p. 457.

with a velocity of 17 to 22 (mile/hour), *i.e.* with a velocity of 33 to 51 along the lake. The sections of the disturbance at Killin and Lochearnhead on the one hand, and at Ardtrostan on the other, were

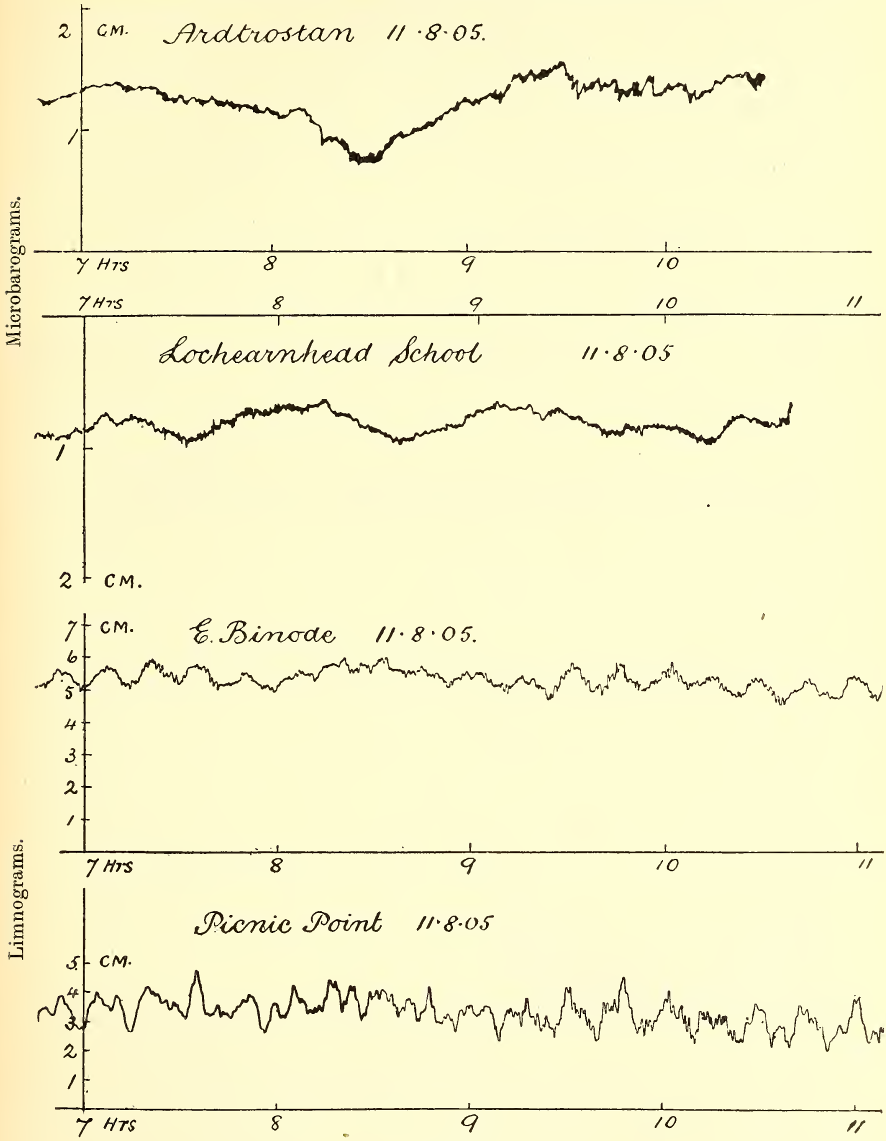


FIG. 25.

very different. The minimum was rounded and pretty flat at the two former places, but cuspidal at the latter. Again, at Killin and Lochearnhead the minimum was followed by a sharp-pointed maximum, with an almost perpendicular rise, while at Ardtrostan the recovery after the minimum is very gradual, and there is only a little wart corresponding to the peaks at the other two stations.

It is interesting to notice that the minimum of the disturbance, although it destroys the configuration of the UB, and generates one of the best-marked BT-dicrotes observed, yet produces no great change in the total range of the seiche. It does produce a small rise of level at Picnic Point of 7 mm. to 11 mm. This is confirmed by the limnogram taken at the binode, where at that time the Sarasin was running at high speed (160 mm. per hour). This shows a rise of

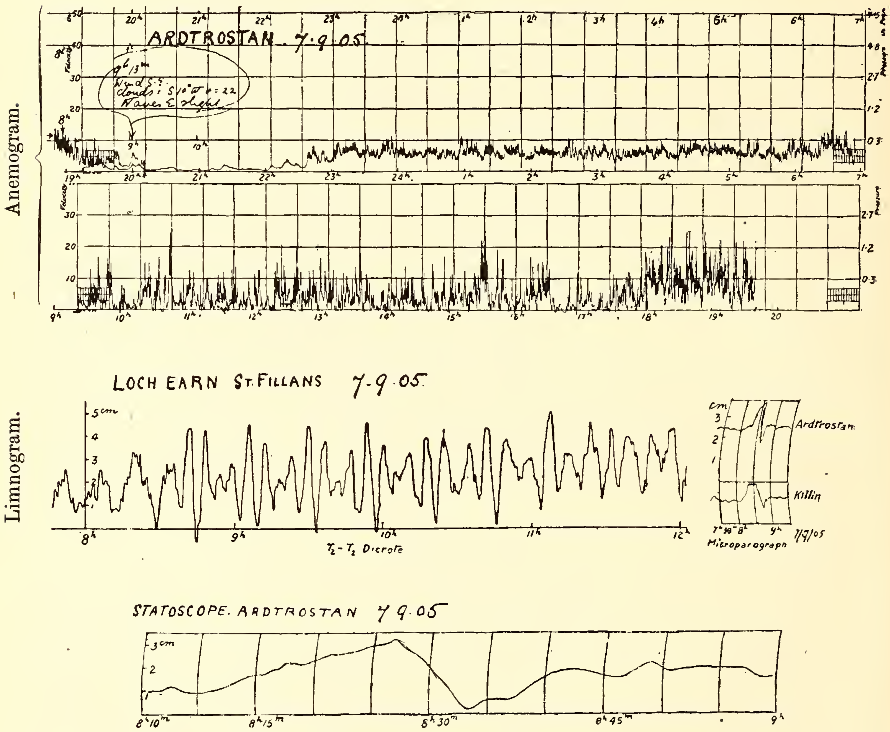


Fig. 26.

level of 5 mm., and a diminution in the range of the uninodal seiche of about 8 mm.

At $14^h\ 13^m$ there is a sudden rise of level of about 14 mm., evidently due to the intense action of the maximum of pressure developed towards the western end of the lake, which there is nothing to counterbalance on the eastern part. It is after this point that the new BT configuration becomes conspicuous. As will be seen from the anemogram, the barometric and seiche disturbances at 14^h were associated with a very sudden rise in the average wind velocity from 5 to 25 (mile/hour).

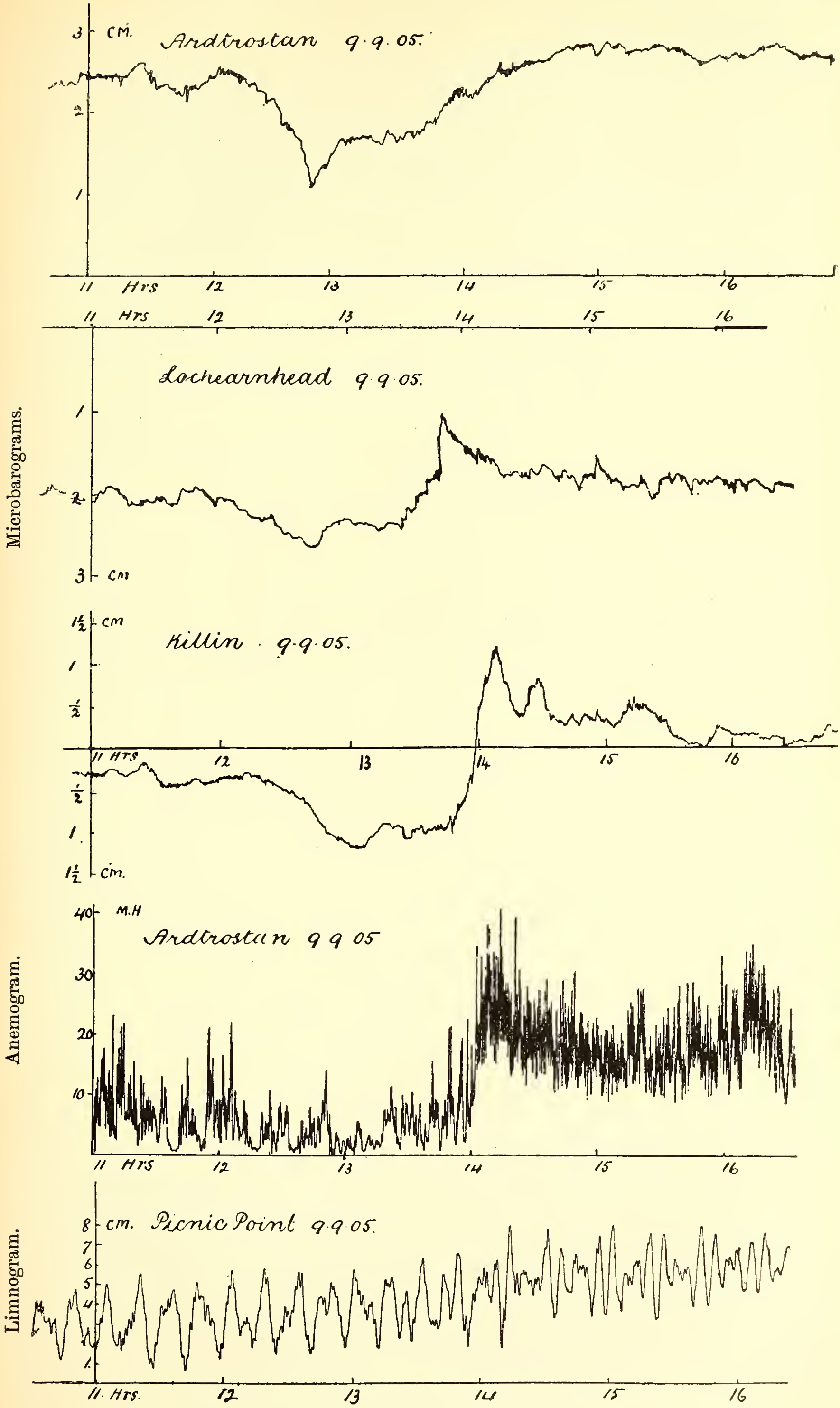

Ardtrostan 9.9.05.
CM.
Hrs
Lochearnhead 9.9.05.
cm
Killin 9.9.05.
cm
HRS
Ardtrostan 9 9 05
M.H
HRS
Picnic Point 9.9.05.
cm.
Hrs.
Microbarograms.
Anemogram.
Limnogram.

Fig. 27.

The Glen Ogle Storm.—One more instance of the connection between abrupt barometric and seiche disturbances may be given, as it was one of the most remarkable observations made on Loch Earn.

On 23rd August, after a dead calm during the night and heavy rain in the early morning, at 8^h 20^m there was a light breeze, W., 5 (mile/hour). There was low cumulus on the hills to E. and N.E., but there was bright sunshine, and the clouds (3) in general were high. The main drift was from S.E., but there was a mackerel formation apparently moving in a different direction; also a mare's-tail showed to S.W.

The waves were running from W.—a slight swell, diversified by oil bands, which were seen at intervals throughout the day.

From 8^h 20^m to 12^h 30^m the wind was light, fluctuating with a rough period of 1^h. At 12^h 30^m there was a sudden gust of 15 (mile/hour). After that the wind rose somewhat, and fluctuated for about 5 hours between 0 and 13 (mile/hour) mean velocity. It was unusually gusty, and at 14^h 5^m an extreme velocity of 25 (mile/hour) was registered. At this moment a black rain-cloud came down Glen Ogle, and reached over the western part of the lake as far as Ardvoirlich, where it stopped.

At 14^h 50^m there came on a sudden rain-shower, the wind being then W. by S. After this there was rain at intervals till 20^h 18^m, an especially heavy shower at 17^h 20^m.

At 20^h 18^m the wind was W.S.W. and variable.

At 14^h 7^m a microbaric disturbance passed Ardtrostan, travelling with a velocity of 15 (mile/hour) from W. 60° N. (36 along the lake).

One of the Lake Survey staff was looking at the uninodal limnograph, and saw it record the sharp depression shown in fig. 28, just as the squall came up. For some time before, the limnographs at the uninode, binode, and Picnic Point had been drawing almost straight lines. The seiche weather had, in fact, been the calmest known in the two months of observation.

The maximum depression (4 mm.) at the uninode and the maximum elevation (5 mm.) at the binode were nearly simultaneous, the latter apparently following about $1\frac{1}{2}^m$ after the former. Unfortunately, owing to the irregularity of the clock at the uninode, certainty on this point is not attainable.

It seems clear that an abrupt elevation of the surface travelled along the eastern part of the lake. The first rise began at the binode at 13^h $55{\cdot}31^m$, and at Picnic Point at 14^h $5{\cdot}24^m$, that is, $9{\cdot}93^m$ later. The first maximum (5 mm.) is seen at the binode at 14^h $1{\cdot}05^m$, and at Picnic Point at 14^h $10{\cdot}57^m$, that is, $9{\cdot}52^m$ later. The velocity of propagation of the first rise would thus be 6·0 (mile/hour), and of the first maximum 6·3 (mile/hour), and it is interesting to notice that by the time the wave has reached Picnic Point a shallow minimum has developed in front of the maximum. If the wave had travelled as a solitary long wave, it would have taken only about 7^m to travel from the binode to Picnic Point.

After the wave reached St Fillans it seems to have been reflected backwards and forwards between the ends of the lake, at first with a good deal of irregularity, but gradually it developed the character-

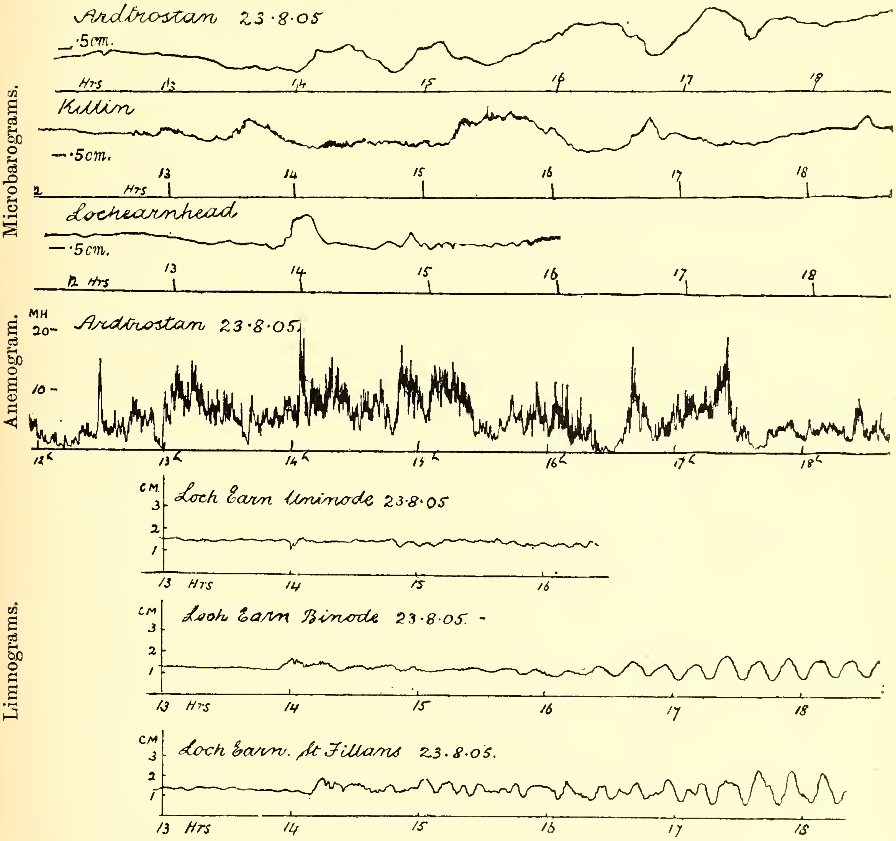


FIG. 28.

istics of a regular dicrote seiche. There are two points (easily seen on the binodal limnogram), viz. 16^h and 17^h 20^m, where the range of the seiche was suddenly increased, evidently by barometric disturbances which occurred at these times. The increase at 17^h 20^m may have been partly due to the heavy shower.

At 17^h 20^m on the 23rd the dicrote is fully developed ($2U = 11{\cdot}5$, $2B = 7{\cdot}0$). It retains its character, with gradually decreasing range, until a little before 24^h on the 24th. About that time the microbarograph at Killin shows disturbances with periods $T = 10^m$,

$T = 15{\cdot}6^m$, and there is an alteration of the UB from $2U = 3{\cdot}7$ mm., $2B = 1{\cdot}7$ mm. to $2U = 11{\cdot}4$ mm., $2B = 1{\cdot}0$ mm. The dicrote then remains steady until 22^h on the 25th, when it undergoes a sudden disturbance, which rapidly destroys its configuration. This sudden disturbance and the almost total destruction of the seiche about 5 hours later are difficult to explain by the meteorological conditions, unless they were due to variations of the wind.

6. Effect of the Impact of Wind-Gusts.—Inasmuch as a wind velocity of 10 (mile/hour) is calculated to produce a pressure of about 1·5 mm. (Aq.) by direct impact on a small area, it is reasonable to expect that the impact of wind-gusts, especially in the case of lakes enclosed by high hills, may at times cause seiches. There are, however, various difficulties in obtaining data on the subject. It is difficult to determine the angle of impact of the wind-blasts. Then it is uncertain whether the wind ever falls at the same angle and at the same time over large parts of the surface of a lake. The appearance of the lake-surface on windy days very often suggests the contrary. What we frequently see are patches of wind disturbance progressing over the lake-surface with varying velocities.

Then again it is difficult to separate the effect of wind impact from the disturbances of the ordinary barometric pressure which always accompany high winds.

It has not been possible to deduce any definite results from the observations under the present head.

7. Effect of Periodic Fluctuations of the Atmospheric Pressure.—The observations on Loch Earn afforded many examples of this cause of seiches. It must, however, be understood that strictly periodic fluctuations of the barometric pressure of short period rarely if ever occur. There are often, however, fluctuations extending over an hour or two in which the undulations are approximately of equal length, and still oftener two or three consecutive undulations of approximately the same length. Such fluctuations are described in what follows as periodic, and by the "period" is meant the average of the intervals between the passage of corresponding phases (say maxima) of two successive undulations at the same point.

It follows from theory, and is confirmed by observation, that a periodic disturbing cause is most effective when its period is not very different from that of the seiche in question. In practice, however, the disturbing effect is considerable even if there is considerable divergence between the two periods. It should also be noticed that, even theoretically, if we consider only one or a limited number of oscillations, and neglect the viscosity, the maximum effect does not correspond to exact equality of the two periods.[1]

[1] See *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 514.

We have already given incidentally some examples of the effect of a periodic disturbing agency, and shall now add a few more.

16*th September*.—About 6^h (see fig. 29) a succession of four very regular waves of barometric disturbance, having a period of $13{\cdot}3^m$,

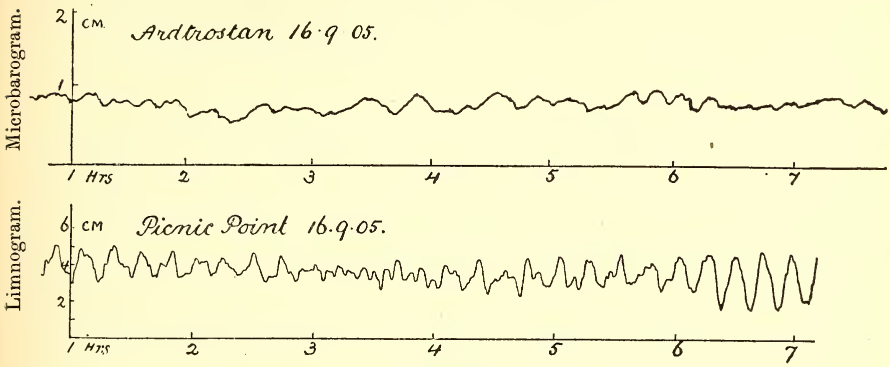


FIG. 29.

generated a very regular UB-dicrote, which lasted about 15^h. The uninodal component gradually diminished, as will be seen from the following measurements :—

Hour.	2U.	2B.
h.	mm.	mm.
Ca. 10	22·9	4·5
,, 16	17·9	4·1
,, 21	9·8	4·2

16*th October*, 4^h–9^h (see fig. 21, above).—A very interesting example, showing both positively and negatively the effect of a periodic barometric disturbance, is obtained by contrasting the limnograms taken simultaneously on Loch Tay at Killin, and on Loch Earn at Lochearnhead. The period of the microbaric disturbance is about 29^m, and it will be observed that it greatly increases the uninodal seiche of Loch Tay, the period of which is about $28{\cdot}4^m$. Indeed, the uninodal thus produced was the best found on Loch Tay. On the other hand, this strong barometric disturbance produces little or no effect on the smooth UB-dicrote which was in progress on Loch Earn, because the periods of its components are $14{\cdot}52^m$ and $8{\cdot}09^m$.

25*th October*, 3^h–8^h (fig. 30).—Microbaric disturbances of period $7{\cdot}5^m$ to $8{\cdot}0^m$ brought out the binodal of Loch Earn ($T_2 = 8{\cdot}09^m$) and the quadrinodal of Loch Tay ($T_4 = 8{\cdot}6^m$).

7th December, ca. 14^h 30^m (fig. 31).—About this hour was observed the greatest total range of seiche found on Loch Tay, viz.

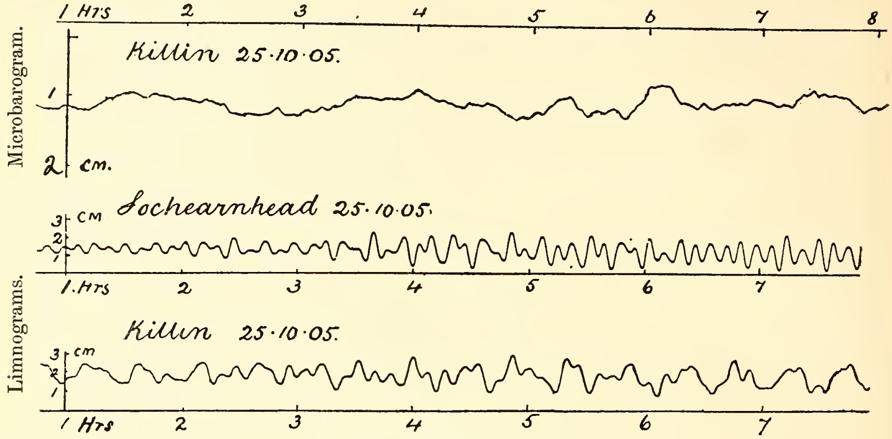


Fig. 30.

80 mm. At that moment the range on Loch Earn, which at 8^h had been as much as 55 mm., was only about 25 mm. The explanation of

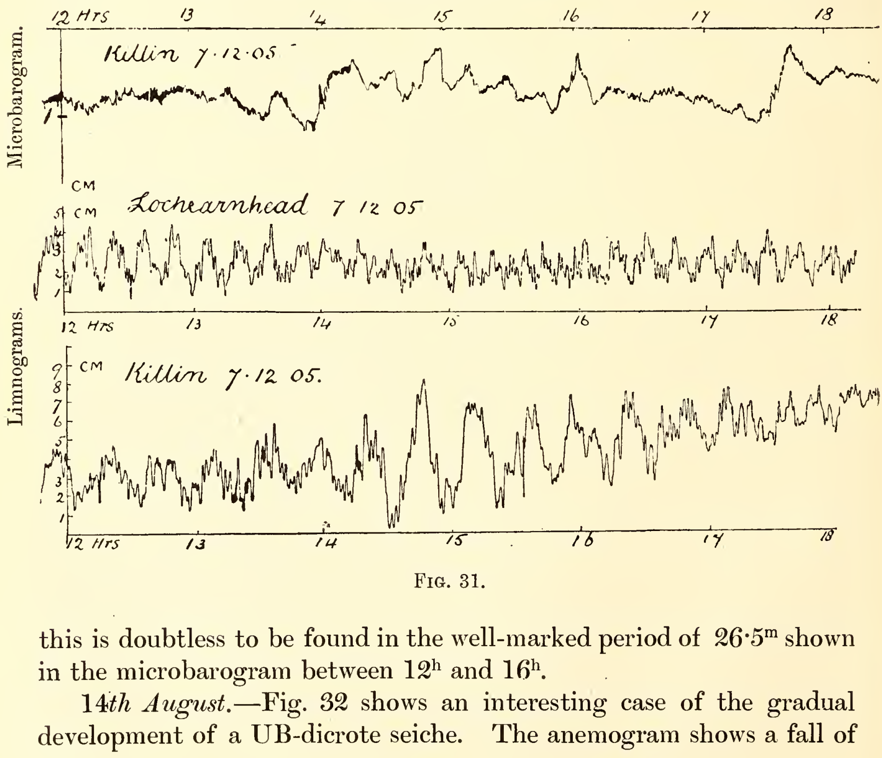


Fig. 31.

this is doubtless to be found in the well-marked period of 26·5^m shown in the microbarogram between 12^h and 16^h.

14*th August.*—Fig. 32 shows an interesting case of the gradual development of a UB-dicrote seiche. The anemogram shows a fall of wind during this development, but it seems to have been too gradual to be the effective cause of the seiche. There can be little doubt that the true cause was a periodic microbaric disturbance, which is very faintly indicated in the microbarograms taken at Ardtrostan and Lochearnhead.

The present is one of many examples found in the course of the observations which prove that a lake-surface is much more sensitive to minor fluctuations of the atmospheric pressure than any barometric apparatus hitherto constructed.

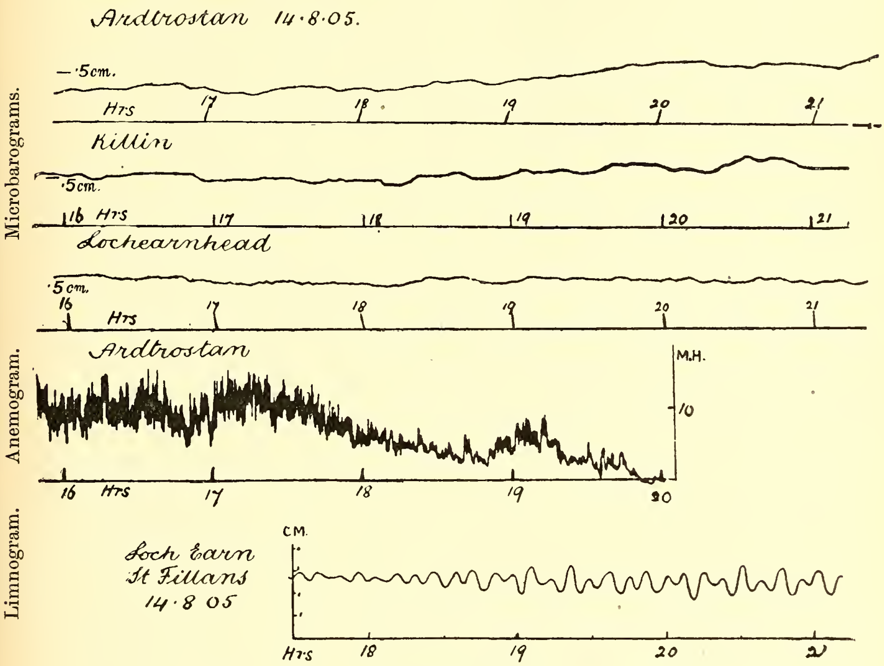


Fig. 32.

Many more examples might be produced, but probably the above are sufficient to establish that the synchronism of quasi-periodic disturbances of the atmospheric pressure with the seiche-periods of a lake is a frequent cause of seiches. It is true that the resonance experiments which Nature performs in her own rough laboratory have not the nice exactitude of those devised and carried out in a physical institute. But then it is not the way of Nature to flaunt her beauties before the unappreciative, or to press the secret principles of her action upon the attention of the unreflecting.

Laboratory Experiments illustrating the Origin of Seiches

The method of generating seiches by stirring at the nodes, which was described above (p. 41), probably does not correspond to anything observable under ordinary circumstances in a lake;[1] but the experiment is interesting in view of the important discovery recently made by the Japanese observers,[2] that the secondary oscillations in many of the bays on the coast of Japan are seiches, having a node at the mouth and a loop at the bottom of the bay. These oscillations, which are sometimes of considerable range, are apparently due to resonance with comparatively inconspicuous undulations in the external oceanic swell, the periods of which are equal to some of the natural periods of the bay.

It was also possible, by means of a trough like that described above, but of different dimensions (length, 5 feet; breadth, 4 inches; depth, 5 inches; depth of water, 3 inches), to illustrate during a lecture at the Royal Institution the generation of seiches in an ordinary lake by periodic variations of the surface pressure. By laying a sheet of tin on the top of the trough, an air-channel was formed over the surface of the water. Through this channel air could be blown by means of a Blackman's fan, and, by working a slider timed by the metronome, the air-current could be made intermittent. When the whole of the surface was covered over by the sheet of tin, the effect of the current, whether steady or intermittent, was merely to generate a train of progressive surface waves. But, when only half the length of the miniature lake was covered in, an intermittent current having the proper period generated a uninodal seiche. When a strip of tin dipping into the water at the end of the covering sheet just over the middle of the water was used to block the air-current, after a few alternations of the blast the amplitude of the generated seiche was such as to cause the water to splash over the ends of the trough.

In like manner, by covering in the tank up to the theoretical position of the binode, a binodal seiche was generated, the parabolic surface of which at its culmination had about the same curvature as the parabolic bottom of the trough.

On the Vibrations which cause the Embroidery on the Limnogram

To the oscillations of a lake-surface having a period of less than 2^m, which under certain circumstances cause a regular or irregular embroidery on the limnogram, Forel gave the name of vibrations. The complete explanation of these vibrations can hardly be said to have been given as yet. They are, however, of great interest, because

[1] Endrös, however, has given examples in point, in some cases of constricted lakes, where a seiche in one part forces a seiche of the same period in another part.

[2] "Secondary Undulations of Oceanic Tides," by Honda, Terada, Yoshida, and Isitani, *Journal of the College of Science, Imperial University, Tokio*, vol. xxiv. p. 1 (1908).

there is some reason to believe that in part at least they reflect in miniature the action of the causes which produce the storm-waves of the ocean, our knowledge of which is still far from complete, although they are of such vital importance to seafaring men.

Inasmuch as our first object was to determine as accurately as possible the seiche-periods and the positions of the nodes of Loch Earn, the limited time at our command was allotted and our apparatus disposed mainly for these two purposes, and it was not until near the end of our observations, after the extemporisation of the statolimnograph, that much attention was given to the vibrations of the lake. We cannot, therefore, pretend to offer much towards a final solution of the problem of the vibrations; but we may record a few observations which seem to enhance the interest of the question, and may ultimately prove useful in its final solution.

The embroidery caused by these vibrations, as may be seen by studying some of the figures in this article, varies considerably in form, and may be regular or irregular according to circumstances. It must also be remembered, as was long ago pointed out by Forel, that, owing to the damping effect of the well and access tube, each limnograph reproduces more or less of these vibrations according to its adjustment. The statolimnograph, used with a wide access tube, owing to the very small inertia of its moving parts, is best adapted for this purpose.

Although occasionally the embroidery continues regular for a considerable time, and appears to have a perfectly definite period and constant or at least slowly varying range, as a rule its configuration changes rapidly, and any regularity is transient. This makes it very difficult to analyse it into harmonic components, even if analysis into a finite number of such components were possible.

In our observations the maximum range of the vibrations varied from 0 to 21 mm.; an average value might be about 6 mm. At times the range of the vibrations (*e.g.* fig. 33) exceeded the range of the seiche, so that the former quite obscured the latter.

The periods observed showed much less variation. In the limnograms taken with the waggon recorder and Sarasin instruments, the period ran from $1{\cdot}3^{m}$ to 2^{m}; in the statolimnograms, from $\cdot42^{m}$ to $\cdot79^{m}$. It must be remembered, however, that in the latter the short-period embroidery obscures that of longer period, and in the former the vibrations of shortest period are damped out. For the ordinary limnograms the average of the periods might be put at $1{\cdot}47^{m}$. The period that actually occurred oftenest in the cases examined was $1{\cdot}5^{m}$.

The embroidery was never observed unless there had been sufficient wind to cause progressive surface waves, and it subsided at once when these waves disappeared. The observations of Halbfass, Endrös, and others show that it is usually more marked when the limnogram is taken at the leeward end of the lake: it may be very marked there and almost or altogether absent at the windward end. It also depends on the amount of shelter at the point of observation.

In most cases the occurrence of embroidery is accompanied by the

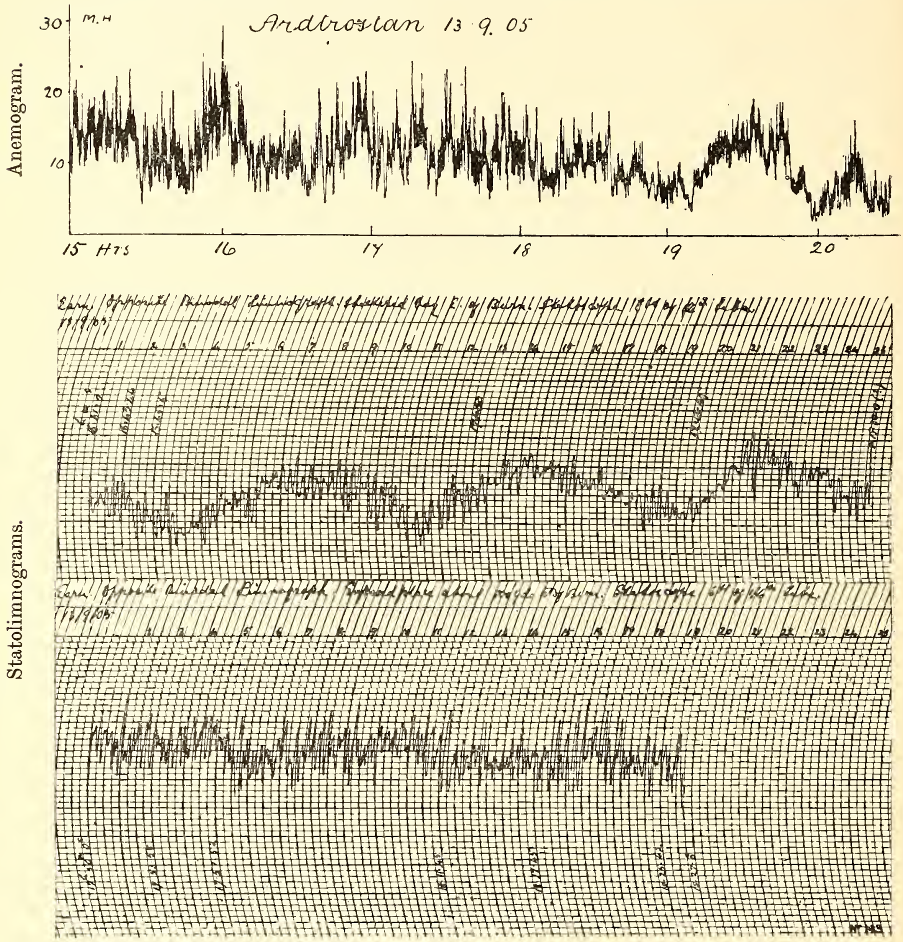


Fig. 33.

characteristic wind blurring on the microbarogram, or else by fluctuations of very short period and very small range. In some cases the fluctuations could be counted, and in one or two their period seemed to coincide with the period of the lake vibrations. The sensibility of the microbarographs used and the number of interpretable cases were not sufficient, however, to justify any general conclusion.

Attempts were made to connect the periods of the lake vibrations with the periods of the wind fluctuations, as indicated on the anemogram, but without success, possibly owing to the fact that the time scale of the anemograph was so short that it was impossible to count the wind fluctuations with any certainty.

The simultaneous limnograms taken on Lochs Earn and Tay during October and November 1905 were examined to see whether there was any connection between the vibrations on the two lakes pointing to a common atmospheric cause. It was found that the average of the maximum ranges and of the periods was much the same for both lakes, but there seemed to be no connection between the occurrence of a particular range or a particular period in the two. The range might be high in both lakes and the periods different; or the periods nearly the same and the ranges different; or there might be vibrations of considerable range on one of the lakes, and none, or only the merest tremor, on the other.

Several suggestions have been or may be made regarding the nature of these lake vibrations.

1. They might be longitudinal seiches of very high nodality. This was the suggestion put forward tentatively by Forel, after trying in vain every other explanation that occurred to him.

If the period of $1{\cdot}47^{m}$ were due to a longitudinal seiche, the number of the nodes would be 12 or 13. It is easy, by regarding Loch Earn as a symmetrical rectilinear lake,[1] to calculate roughly the positions of the nodes. It would therefore be possible, by means of careful experiments with two or more self-registering instruments, such as the statolimnograph, to obtain positive or negative evidence regarding the truth of the hypothesis that the vibrations are wholly or partially plurinodal longitudinal seiches.

In the present state of knowledge the balance of evidence seems to be against this hypothesis. A plurinodal seiche is a simultaneous oscillation of the whole lake. If, therefore, a vibration were a plurinodal seiche, it should be apparent simultaneously at both ends of the lake, whereas we know that it may be present at either end and apparently absent at the other. Also, if it be a plurinodal seiche, it should be present simultaneously at nearly opposite points on the two sides of the lake.

Repeated attempts were made to detect correlations of phase, by stationing observers on the two sides, and signalling the maxima or minima of the vibrations; but it was quite impossible to establish either coincidence or opposition of phases. Observations were also made with the statolimnograph at a point opposite the limnograph near the eastern binode, while the latter was running at high speed (2·96 mm. per minute). Not only were there no apparent coincidences

[1] See H.T.S., p. 639.

of phase, but the binodal limnograph showed a well-marked vibration whose period was 1·35^{m}, while the best-marked period of the embroidery on the statolimnogram was ·44^{m} to ·47^{m}.[1]

2. The vibrations might be transversal seiches of the lake. In my memoir on the Hydrodynamical Theory of Seiches I expressed some doubt whether seiches of this kind could be stable in an elongated lake. But in a paper already mentioned[2] Dr Endrös has stated that he has, by means of phase observations, definitely established the existence of a transversal seiche of period 1·56^{m} in the Tachinger See, and shown that both it and the seiche between Morges and Evian, observed by Forel and suspected by him to be transversal, as well as certain other cases of the same phenomenon, agree very well with the hydrodynamical theory. My doubt on this matter must therefore be abandoned. Dr Endrös' view is that only part of an elongated lake takes part in the transversal oscillation, and that the establishment of a cross seiche is favoured by the existence of bays on the two sides of the lake, the ends of which determine the axis of the seiche. This view is strongly supported by the results of the Japanese observers regarding secondary tidal oscillations in the bays of the coast of Japan already referred to.

There remain, however, two difficulties as regards Loch Earn. I have calculated by means of a parabolic approximation the periods of the cross seiches for various breadths of Loch Earn, and find values which average 1·85^{m}, the smallest being 1·83^{m}, the greatest 2·30^{m}. The section at the eastern binode, where the observations above referred to were made with the statolimnograph and the Sarasin limnograph, is very nearly parabolic in shape, and the period there would be 1·9^{m} or more, which exceeds any of the periods observed in the embroidery by more than any likely error, either of observation or calculation.

Then there is the further fact, already mentioned, that no correspondence of phase could be detected, although it was anxiously looked for, and indeed at first expected.

3. Another cause of the embroidery of the limnogram may possibly be found in progressive surface waves and wave groups.

Everyone is aware that the effect of a persistent wind, which has blown for some time along a lake-surface, is to produce a progressive train of waves travelling down the wind. The height and also the length of these waves depends on the "fetch," *i.e.* the length of water over which the wind has blown, as well as on its velocity. The range and the wave-length both increase as we go "down the wind," until at last the wave-crests break and "white horses" are formed. Then a sort of dynamical equilibrium is established, and the range and

[1] See fig. 33, where the statolimnograms in question are reproduced.

[2] *Petermann's Mitt.*, Heft ii., 1908.

wave-length increase no longer, unless the waves run into shallow water. This progressive surface wave motion may persist for a considerable time (in the ocean for days) after the wind has fallen, in the form of swell, and it may be propagated into regions where there has been no wind. In ordinary circumstances, owing to the continual variation in the strength of the wind, and in the case of lakes probably also to reflections from the shores, at any particular moment not one train of waves is generated, but many of slightly differing wave-length and differing phases. These trains interfere and cause a succession of wave maxima, commonly called "wave groups."

Several observations of the periods of surface waves and wave groups on Loch Earn were made by counting the waves or wave maxima which passed a given point in a certain time. This is easy in the case of the wave maxima; not so easy in the case of the single waves, which have a bewildering habit of losing themselves by running into and through each other and through the maxima. Still, the results were fairly concordant. The observations were made at the eastern binode and at Picnic Point during westerly winds of various kinds. The average of the periods for single waves was $\cdot035^{m}$, the smallest and greatest values being $\cdot024^{m}$ and $\cdot045^{m}$. The most usual value of the period for the groups was $\cdot5^{m}$ to $\cdot66^{m}$, the least and greatest values observed being $\cdot33^{m}$ and $1\cdot17^{m}$. For the single waves ranges of 6 in. to 12 in. were common; but on one stormy day ranges of 2 ft. to 3 ft. were observed.

From a set of observations made at my request by Mr James Murray on Loch Tay, the following data were calculated for that lake. T is the period, λ the wave-length, and v the velocity of propagation for the single waves; T_g, λ_g, v_g, the corresponding magnitudes for the wave groups. The observations were made at Killin, when there was no wind, on swell coming in from the lake and running in water 13 ft. 6 in. to 12 ft. deep.[1]

For Single Waves

$T = \cdot017^{m}$, $\lambda = 18$ ft. to 25 ft., $v = 18$ to 25 (ft./sec.) $= 12$ to 17 (mile/hour).

For Larger Groups of 4 to 6 Maximum Waves

$T_g = \cdot5^{m}$ to $\cdot75^{m}$, $\lambda_g = 252$ ft. to 283 ft., $v_g = 8\cdot4$ to $6\cdot3$ (ft./sec.) $= 5\cdot7$ to $4\cdot3$ (mile/hour).

For Smaller Groups of 2 to 3 Maximum Waves

$T_g = \cdot083^{m}$ to $\cdot17^{m}$, $\lambda_g = 42$ ft. to 63 ft., $v_g = 8\cdot4$ to $6\cdot3$ (ft./sec.) $= 5\cdot7$ to $4\cdot3$ (mile/hour).

[1] The velocity of a "long wave" in which would be about 20 (ft./sec.).

It is obvious that the single waves could not cause the ordinary and most prominent periods in the embroidery, which run from about $\cdot 5^m$ to $1\cdot 5^m$; but there is no doubt that they cause the thickening or blurring of the limnogram which usually appears when the wind is high. On the other hand, the periods of the wave groups are nearly coincident with some of the more prominent periods of the embroidery. Part of this embroidery may therefore be due to wave groups, but more observations are required to settle the matter beyond doubt.[1]

4. In a paper "On the Relation between the Velocity of the Wind and the Dimension of Oceanic Waves, with an Explanation of the Waves of Longer Period on Open Coasts,"[2] Professor Börgen has suggested that the secondary tidal oscillations and waves of unusually long periods occasionally observed on open coasts, where the circumstances do not seem to justify the assumption of a seiche, may be due to difference and summation waves (whose theoretical existence arises from the non-applicability of the theory of the linear superposition of small motions). Such waves would be analogous to the difference and summation tones of Helmholtz. It is quite possible that an explanation of this kind may apply in part to lake

[1] It is much to be desired that further observations should be made on the period, wave-length, and velocity of propagation of single waves and wave groups, in lakes, on sea-coasts, and in the open sea. Sailors have many opportunities for such observations; and physicists might devote some attention to the matter, when they take an open-air vacation from the ardent pursuit of the electron. It is curious how ignorant we still are regarding some of the most important hydrodynamical phenomena, notwithstanding something like a century and a half of continued researches, both mathematical and experimental. We know very little, for example, regarding the action by which the wind increases the range and the length of the waves as we pass to windward.

We are told (see Lamb's *Hydrodynamics*, p. 569, 1906), and it is easy to understand, that a wind whose velocity is greater than the velocity of progression of a train of waves must increase their range; but what is the explanation of the increase of wave-length? Observations, some of which are mentioned below, have strongly suggested the following as the *modus operandi*:—The dynamic instability of the surface after the wind has reached a certain velocity leads to the generation of wave trains of slightly varying length and phase. These trains interfere and produce wave maxima. The wind, so long as it travels faster than the wave maxima, will increase the range of the waves near the maxima more than elsewhere. Thus the periodically occurring wave maxima will be elevated into independent wave trains no longer resolvable into the previous harmonic components. Thus a new train of progressive waves will be formed of considerably greater mean range and mean wave-length than before, but of slightly differing ranges and wave-lengths. These again will interfere, and through the action of the wind generate other trains of still greater mean range and mean wave-length; and so on, until the process is stopped by the breaking of the wave crests. This is merely a speculation, without sufficient basis, either theoretical or experimental; but the subject seems to call for investigation, and its practical importance is undeniable.

[2] *Annalen der Hydrographie und maritimen Meteorologie*, Heft i., 1890.

vibrations, but we have no evidence to produce for or against such a hypothesis.

5. Towards the end of the survey of Loch Earn, some observations were made with the statolimnograph (unfortunately there was time to make only a few) which point to yet another explanation of some part, especially the more irregular part, of the embroidery on the limnograph.

In fig. 33 are placed together two statolimnograms, which were taken in close succession at two stations near to each other on the northern shore of Loch Earn, during a moderate westerly breeze [mean velocity 12 to 16 (mile/hour), extreme velocity occasionally 24 (mile/hour)]. The upper one was taken in a sheltered bay to leeward of the delta of the Glentarken Burn, the lower about 100 yards farther west, to windward of the delta. The bay was comparatively calm, disturbed only by the swell propagated into it from the wind waves rolling outside. The difference between the two limnograms is very striking. The maximum range of the embroidery to windward is much greater, and the pattern is much more irregular and complicated. What remains to leeward has much the same prominent periods as observed to windward, viz. $\cdot 4^m$ to $\cdot 5^m$, but it is obvious that the intervening promontory has screened off a great part of the vibrations. The part thus screened off could only consist of surface waves of short length, and could not consist either of longitudinal or of transverse seiches.

Again, I often watched the statolimnograph slowly inscribing indentations, such as those which are so marked in the lower limnogram in fig. 33, and noticed over and over again that it would set one down in an interval of total or comparative calm. On looking to windward when this happened, a black line would be seen on the water some distance off, indicating a coming wind-squall; then presently would be heard the rustle of the wind in the trees overhead, and the increased prattle of the waves among the pebbles on the beach would show that the squall had reached the observer. In short, the lake-vibration had gone before, and the wind had followed after. The explanation seems to be that the squall exerts a horizontal traction on the water and causes a drift current. By and by this current becomes greater than the compensating return current underneath. Thus a hump (or a group of waves) is raised on the surface, which is propagated in the water with a speed usually exceeding the velocity of the wind in a moderate breeze. This is, in fact, in small a phenomenon with which sailors are familiar on a large scale, when they point to the long swell which records or presages a distant storm at sea.

I obtained a striking confirmation of this view in the course of an observation planned to test a totally different hypothesis. I had supposed that the vibrations might be due to some extent to simultaneous abrupt or periodic disturbances of the atmospheric pressure. As explained above (p. 36), the statolimnograph can be used in rapid alternation as a limnograph and as a microbarograph. Fig. 34 shows the result of an observation of this kind. The limnogram is deeply embroidered; the microbarogram is all but straight. Since the sensitiveness of the Richard statoscope is fifteen to twenty times that of a mercury barometer, the ordinate of the microbarogram represents the air-pressure on a larger scale than a water barometer. If we allow for the damping effect of the well and access tube on the half-minute vibrations, we shall be under the mark if we admit that

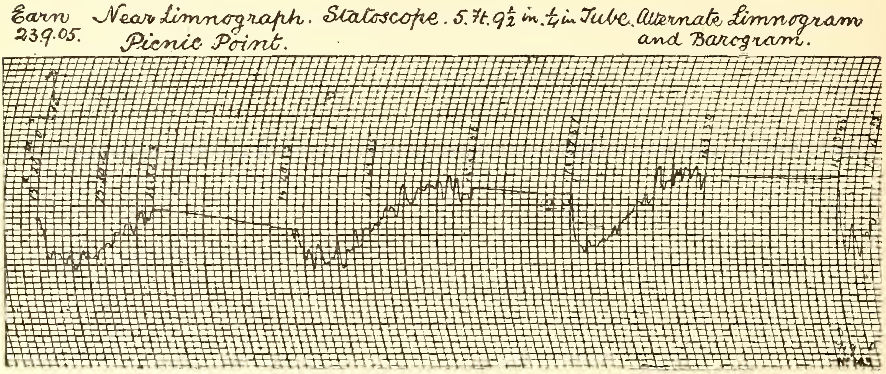


Fig. 34.

the statolimnograph magnified the range of these vibrations three times. The obvious conclusion is that there was no disturbance of the atmospheric pressure of an order sufficient to cause directly the embroidery observed on the limnogram. It follows that it must have been due to some cumulative atmospheric cause whose action originated at a distance from the observers, and I am inclined to look for this cause in the surface waves, solitary or periodic or quasi-periodic, caused by the heaping action of the wind. It is, of course, obvious that such action as this would be screened off by a promontory or an island, and would be most marked at the windward end of a lake. This cause was suggested, under the name of *Windstau*, by Endrös in his classical memoir on the complicated seiches of the Chiemsee, which has done so much to enlarge our knowledge of lake oscillations.

TEMPERATURE OF SCOTTISH LAKES

By E. M. WEDDERBURN, W.S.

History of Temperature Observations in Scottish Lakes

Scotland holds an honourable position in the history of the rise of Limnology as a science, and only yields the first place to Switzerland in this respect.

The first observations on the temperature of the water in deep lakes were made by Saussure, and the careful manner in which they were made is described by him in his *Voyages dans les Alpes*, 1779-1796. The first observations on the temperature of Scottish lakes were not much later, for in the years 1812 and 1814 Mr James Jardine, C.E., carried out series of observations at different depths in Loch Tay, Loch Katrine, and Loch Lomond, which were published by the late Dr Alex. Buchan in 1872.[1] These observations were also described by Sir John Leslie in 1838 in his *Treatise on Various Subjects of Natural and Chemical Philosophy* (Edinburgh, 1838, p. 281), and in the article "Climate" by him in the eighth edition of the *Encyclopædia Britannica* (vol. vi. p. 777), where he expressed the view (now shown to be erroneous) that the seasonal variation of temperature in deep lakes was limited to fifteen or twenty fathoms.

As these observations were the first to be made in Scotland, it may be of interest to quote Sir John Leslie's account of them, especially as it shows that, although one of the earliest writers on lake temperatures, he had grasped the essential elements of the subject:—

"But the rays which fall on seas or lakes are not immediately arrested on their course; they penetrate always with diminishing energy, till, at a certain depth, they are no longer visible. This depth depends without doubt on the clearness of the medium, though probably not one-tenth part of the incident light can advance five fathoms in most translucid water. The surface of the ocean is not, therefore, like that of the land, heated by the direct action of the

[1] *Proc. Roy. Soc. Edin.*, vol. vii. p. 791.

sun during the day, since his rays are not intercepted at their entrance, but suffered partially to descend into the mass, and to waste their calorific power on a liquid stratum of ten or twelve feet in thickness.

"But the surface of deep collections of water is kept always warmer than the ordinary standard of the place, by the operation of another cause, arising from the peculiar constitution of fluids. Although these are capable, like solids, of conducting heat slowly through their mass, yet they transfer it principally in a copious flow by their internal mobility. The heated portions of a fluid being dilated, must continue to float on the surface; while the portions which are cooled, becoming consequently denser, will sink downwards by their superior gravity. Hence the bed of a very deep pool is always excessively cold, since the atmospheric influences are modified in their effects by the laws of statics.

. . . .

"Through the friendship of Mr James Jardine, civil engineer, we are enabled to give the results of his observations on some of the principal Scottish lakes, which, as might be expected from him, were conducted with the most scrupulous accuracy. The instrument which he employed for exploring the temperature at different depths, was free from the ordinary objection; being a register thermometer, let down in a horizontal position, which could acquire the impression in not many seconds, and might be drawn up leisurely, without risk of subsequent alteration. It would appear that the variable impressions of the seasons do not penetrate more than 15 or 20 fathoms; that below this depth, an almost uniform coldness prevails. Thus in the deepest part of Loch Lomond, on the 8th September 1812, the temperature of the surface was 59°·3 of Fahrenheit; at the depth of 15 fathoms, 43°·7; at that of 40 fathoms, 41°·3; and from that point to about 3 feet from the bottom, at 100 fathoms, it decreased only the fifth part of a degree. Again on the preceding day, the superficial water of Loch Katrine being at 57°·3, the thermometer, let down to 10 fathoms, indicated 50°·6; at the depth of 20 fathoms it marked 43°·1; at the depth of 35 fathoms it fell to 41°·1; and on the verge of the bottom, at 80 fathoms, it had only varied to 41°. At the same place, on the 3rd September 1814, the heat of the surface was 56°·4; at the depth of 10 fathoms, 49°·2; at that of 20 fathoms, 44°; at that of 30 fathoms, 41°·9; and at that of 80 fathoms, 41°·3."

Jardine's observations stand by themselves in Scotland for a period of nearly sixty years, although the study of lake temperatures was engaging attention on the Continent and in America; but Sir Robert Christison revived interest in the matter by describing, in his Presidential Address to the Royal Society of Edinburgh in 1872,[1] observations which he had made in Lochs Lomond, Tay, and Katrine during the years 1870 and 1871. Sir Robert Christison demonstrated the existence in these lochs of a substratum of relatively cold water of considerable thickness, which underwent little or no seasonal change. He also noted the existence of a discontinuity between the temperature of the upper and lower layers of water, which has been found to play such an important part in the temperature of fresh-water lakes.

Dr Buchan[2] next interested himself in the observations of Jardine and Christison, and by a comparison of the temperature of the cold substratum with the mean temperature of the air, he arrived at the conclusion that it is the mean temperature of the cold half of the year which determines the temperature of the lowest stratum in deep lochs.

On the return of the *Challenger* Expedition Mr J. Y. Buchanan took up the study of lake temperatures, and his explanation of the manner in which ice is formed on lakes was another step in the advance of limnology. But perhaps the most important contribution to the literature of the subject during last century was Sir John Murray's paper, published in 1888, on the effect of winds on the distribution of temperature in the sea and fresh-water lochs of the west of Scotland.[3] Dr John Aitken was interested in Buchanan's observations, and drew attention[4] to the importance of wind currents in reducing the temperature of lakes considerably below the maximum density point before freezing took place, and may justly be considered one of the pioneers of lake-temperature investigations; but previous to Sir John Murray's investigations very little account was taken of the effect of wind on the temperature distribution of lakes, and Continental limnologists do not yet seem to have realised the importance of the facts brought to light by him. From that date onwards there has been a considerable quantity of observations, made, amongst others, by Sir John Murray, Mr J. Y. Buchanan, and Dr H. R. Mill, which materially add to our knowledge of the distribution of temperature in lakes.

About the year 1897 the late Mr Fred. P. Pullar began a systematic survey of the lochs of Scotland in conjunction with Sir John Murray, and their scheme of work included an examination of the temperature conditions of various lochs surveyed. After his death

[1] *Proc. Roy. Soc. Edin.*, vol. vii. p. 567.
[2] *Op. cit.*
[3] *Scott. Geogr. Mag.*, vol. iv. p. 345.
[4] "The Distribution of Temperature under the Ice in Frozen Lakes," *Proc. Roy. Soc. Edin.*, vol. x. p. 409, 1880.

the survey was carried on under the direction of Sir John Murray and Mr Laurence Pullar, and temperature observations were made in practically all the lochs surveyed. In Loch Ness observations were made in the years 1903, 1904, and 1905, which in their completeness are, I believe, unique in the history of limnology, though in the light of after experience the observations leave much to be desired. I have subsequently endeavoured to examine the temperature changes occurring in fresh-water lakes experimentally, and during the first half of the year 1908 I was able to make numerous observations in Loch Garry, Inverness-shire, which are of great value as confirming deductions based on the observations in Loch Ness. An attempt has also been made (the first of its kind) to observe directly currents in lakes, with a view to a better understanding of the temperature changes which have been observed.

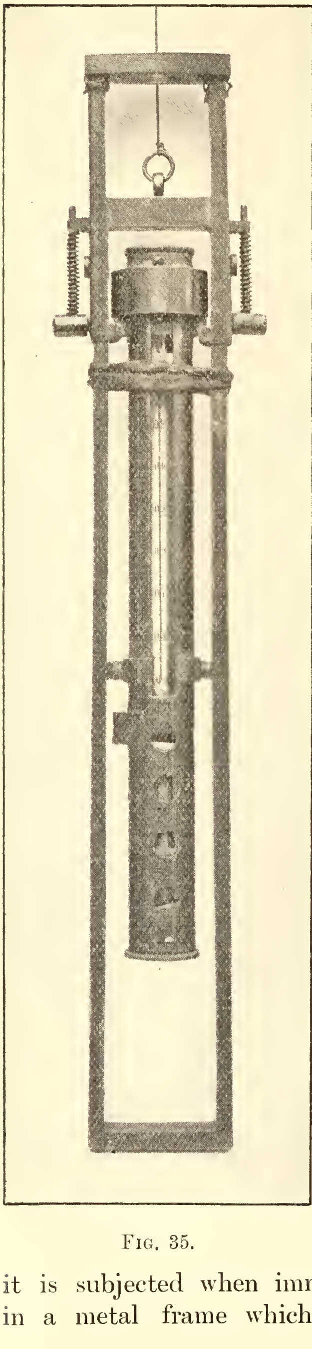


Fig. 35.

Reference may be made in passing to the different kinds of thermometers which have been used from time to time in making temperature observations in lakes. The instrument which is chiefly used now is the Negretti & Zambra reversing thermometer. It consists of a mercury thermometer with a constriction in the bore of the stem about an inch above the bulb. As long as the thermometer is upright the mercury is continuous from bulb to stem, but if the thermometer be turned upside down, the mercury breaks at the constriction, and the portion in the stem falls down. The stem is graduated from the point to the bulb, so that the temperature at the moment of inversion is read off on the stem. This thermometer is enclosed in a strong glass case to protect it against the pressure to which it is subjected when immersed in water, and the whole is fitted in a metal frame which can be attached to the sounding-line.

The forms of the frame for the reversing thermometer are various, one of the forms largely used by the Scottish Lake Survey having been designed by the late Mr Parsons (see fig. 35), at one time engaged on the Survey, and afterwards principal mineral surveyor in Ceylon; but the essence of all the frames is that on a spring catch being released the thermometer is inverted. In the usual form of frame the spring is released by allowing a weight, called a messenger, to slide down the sounding-line till it strikes the thermometer frame. The form of messenger to which I am most partial is a bar of metal twisted into a spiral, which can then be wound on to or off the sounding-line without fear of loss (see fig. 36). This form of messenger was designed by Mr William Macdonald, my boatman and observer on Loch Garry. By means of these thermometers observations may be rapidly taken, the rapidity being increased by attaching thermometers to the sounding-line at intervals; two or three or more thermometers may be used on one line at the same time, and thus simultaneous observations of temperature at the several depths may be obtained. The thermometers had, of course, to be immersed for some time to allow of their taking up the temperature of the water surrounding them; and it was found by experiment that, where there were no great differences of temperature in the course of the observations, three minutes was sufficient time to allow.

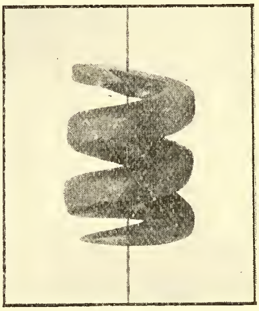


Fig. 36.

The early observers worked under great disadvantages, having to use an ordinary thermometer in one of two ways. In one method a thermometer, with many coats of non-conducting material, was lowered to the desired depth, and left for many hours to take up the temperature of the surrounding water. The protective coatings prevented any appreciable alteration in the temperature while being raised to the surface, and the thermometer could then be read. The other method was to bring up a sample of water from the desired depth in a suitable form of bottle or bucket, and then measure the temperature of the water when it reached the surface. It will be at once apparent that these methods were far from perfect, but in the hands of observers like Saussure they were used with great accuracy, and the observations may be relied on implicitly.

Subsequently many varieties of self-registering thermometers adapted for observing deep-water temperatures were designed, but in connection with these it is only necessary to mention the names of Cavendish, Six, and Aimé. The Millar-Casella maximum and minimum thermometer, which is a form of Six's thermometer, is frequently used for observing deep-water temperatures; but a maximum and minimum thermometer can only be used where it is known that there is a continuous rise or fall in temperature from the top to the bottom, for the thermometer only gives the maximum and minimum temperatures to which it has been subjected while being lowered and raised, and this is not necessarily the temperature at the depth to which it has been lowered. The reversing thermometer is, however, not open to this objection, as it registers the temperature at the time it is made to turn upside down, irrespective of the temperature of the water through which it passes while being raised or lowered.

During the Loch Ness observations use was made of platinum resistance thermometers in conjunction with a Callendar recorder. Some observations with resistance thermometers had previously been made in America by Mr Warren, who used a telephone to measure the changes in resistance of a platinum thermometer, and one of his instruments was used by the Survey. Dr F. M. Exner[1] also used ingenious electrical resistance thermometers in the Wolfgangsee with considerable success, but no observations on a large scale had previously been attempted by electrical means.[2] The object of the electrical installation was to obtain a continuous record of temperatures at any depth. The arrangement used was designed for the Lake Survey by the Cambridge Scientific Instrument Co., Ltd., and is referred to in my paper on lake temperatures.[3] It was not altogether satisfactory, but the experience gained in working with it would probably enable the observers to design an apparatus which would work well; and this method of observation, giving, as it does, continuous records of the temperature, has great advantages over observations made with mercury thermometers.

Effect of Configuration and Geographical Position on the Temperature of a Lake

It is difficult to enumerate all the factors which play a part in determining what shall be the temperature of the waters of a lake, but these factors may be discussed under the following heads:—(1) the depth of the lake and the area of its surface, (2) its altitude,

[1] "Messungen der täglichen Temperaturschwankungen in verschiedenen Tiefen des Wolfgangsees," *Sitzungsber. Akad. Wiss. Wien*, Bd. cix., Abt. ii.a, 1900. "Über eigentümliche Temperaturschwankungen von eintägiger Periode im Wolfgangsee," *ibid.*, Bd. cxvii., Abt. ii.a, 1908.

[2] A thermo-electric junction was used to measure temperatures in the Lake of Geneva in 1836 by MM. Bequerel and Breschet (*Bibl. Univ. Genève*, t. vii, p. 173, 1837). This is probably the first attempt to measure lake temperatures by electrical means.

[3] See *Trans. Roy. Soc. Edin.*, vol. xlv. p. 410.

(3) its latitude, (4) its orientation, (5) its surroundings, and (6) its general shape.

(1) **The Effect of Depth and Superficial Area.**—The part which the size of a lake plays in the determination of the temperature of its waters may easily be understood by imagining two lakes situated side by side, and thus subjected to similar external influences. In the first place consider the case of two lakes of the same surface area, but of unequal depths. For present purposes it may be assumed that the only channel by which heat enters or leaves a lake is by the surface, so that the two lakes which are to be considered have equal opportunities of gaining or losing heat. But if one lake is deeper than the other it contains a greater quantity of water, the temperature of which will be raised or lowered by the heat entering or leaving the lake by the surface. A concrete example will illustrate my meaning. Assume that the lakes have rectangular basins and that the deeper of the two is 400 feet deep and the shallower 200 feet deep. Further, assume that at the time when they begin to gain heat the waters of the deeper lake have a uniform temperature of 40° and the waters of the shallower lake a temperature of 37°. By the time the water of the deeper lake has an average temperature of, say, 50°, there must have entered through the surface 10V units of heat, where V represents the volume of the lake. As the surface of the shallower lake has the same area, the same quantity of heat should have entered its waters; but as the volume of the shallower lake is only V/2, its mean temperature will have been raised 20° by the 10V units of heat which have entered at the surface. That is to say, its mean temperature will be 57°. This example is very crude and has not much reference to actual facts, but it is sufficient to show the importance of depth in determining the temperature of a lake. In the same way a rough measure of the importance of surface area can be obtained. Consider two lakes similarly placed and of equal volume, but the surface area of the first double that of the second. As the heat is supposed to enter solely by the surface, the first lake will receive twice as much heat as the second; and as the volume of the two lakes is the same, a rise of 20° in the mean temperature of the first lake would correspond to a rise of 10° in the mean temperature of the second. This is, of course, an extreme case, but it serves to illustrate the importance of surface area in determining the temperature of a lake.

The size of a lake has another effect, which is well illustrated by some of the observations in Scottish lakes referred to at the end of this paper (see page 135). The longer and the straighter the axis of a lake is, the more effect has a wind blowing along its surface in mixing the water and producing currents. The ratio of depth to length in a lake has a considerable influence in determining the depth to which wind-produced currents are felt; and it is found that comparatively deep lakes which are small always have a greater range of temperature from top to bottom than longer lakes of equal depth.

(2) **Effect of Altitude.**—The effect of altitude on the temperature of a lake requires no elaboration. Altitude enters into the temperature of the atmosphere, and so into the temperature of the lake, for conduction from the atmosphere is one of the methods in which heat is communicated to a lake. Rarefaction of the atmosphere has also a small effect on the rate of conduction to or from a lake. Lakes at considerable altitudes have usually small drainage areas, and this too must be taken into account; sometimes the quantity of water caught in the drainage area of a lake in the course of a year is sufficient to fill the lake-basin several times over, and it is evident that such a lake cannot be considered a stagnant body of water. The effect of water flowing into a lake, however, is chiefly felt at the surface, and the bottom temperature is not greatly affected, for, in general, drainage water is in summer warmer than the bulk of water in the lake, and in winter colder, and therefore remains on the surface.[1]

(3) **Effect of Latitude.**—In the same way latitude is a factor determining the temperature of a lake, owing to the difference in atmospheric conditions, and in the incidence of the sun's rays brought about by difference in latitude. Difference in latitude produces great changes in the range of temperature to be found in lakes. Thus in the Lake of Geneva the mean surface temperature in the harbour of Geneva for the years 1853 to 1875 for the month of February was 40°·9 Fahr., and for the month of August 65°·6—a range of nearly 25°. In Loch Ness, the means at Fort Augustus for these months for two consecutive years were respectively 41°·9 and 54°·9 Fahr.—a range of only 13°, or little more than half the range in Lake Geneva. And it is not only the yearly range that diminishes with latitude, but also the temperature gradient in the lake. In low latitudes the heating is comparatively rapid, so that much greater temperature gradients are found. Thus in the Wolfgangsee (which is a lake with a maximum depth of 375 feet) from the surface to a depth of 70 feet there was a fall in temperature of 30° Fahr., whereas in Loch Ness a fall of 10° or 11° in a similar distance was all that was found, and the greatest range observed in any Scottish lake was 21°·2 in Loch Achilty (see page 137). As will be seen in the sequel, large temperature gradients such as these have an important bearing on the temperature changes which occur in lakes.

(4) **Effect of Orientation.**—The effect of orientation of a lake is not at first sight so apparent. By orientation is meant the direction

[1] But see pages 100–101.

in which the lake trends—north and south, or east and west. The orientation of a lake is important, as it determines whether the prevailing winds sweep along the whole length of the lake, or whether they merely blow across it. The effect of winds on a lake will be discussed in considerable detail later, but it may be stated that winds are of great importance in determining the temperature distribution, for they are the means of mixing the waters at the surface, which have been heated or cooled, with the deeper layers of water, thus helping to make temperature changes felt to a greater depth than would be possible by conduction or radiation. If the prevailing winds blow along the length of the lake they have a much greater mixing effect than if they merely blow across it.

(5) **Effect of Surroundings.**—It is at once evident that the natural surroundings of a lake are very important. If the lake is surrounded by high hills, as is the case with many of our Scottish lakes, the prevailing winds will nearly always be deflected to blow along the lake, thus exercising a greater mixing effect than if they blew across it or at an angle. Again, one lake may be greatly sheltered from winds by surrounding hills and woods, while another, similar as regards size and shape, may be exposed to every wind that blows. The presence of hills also has its effect in directly cutting off sunshine from reaching the surface of the lake, and in the formation of clouds which obscure the sun.

(6) **Effect of General Shape.**—It is evident that the shape of the basin of a lake has a considerable effect in determining its temperature conditions. The effect of the wind is different in deep and shallow lakes, as already indicated. Lakes with shelving shores also behave differently in some respects from lakes whose shores are steep. Narrow lakes in confined glens cannot be compared with broad and open sheets of water.

These and many other points will be dealt with later, but I may state here that I have been criticised for generalising from a lake such as Loch Ness, which is deep and narrow compared with other lakes. The criticism is fair, but it only shows the necessity for complete observations in lakes of all kinds. Forel insists that each lake has its own individuality, and that only by a careful and complete study of each lake can we approach the truth. Complete observations in a great number of lakes are not available, but it seems improbable that the temperature conditions observed in Lochs Ness and Garry should not have their counterpart in all lakes.

Methods by which a Lake Gains or Loses Heat

What are the methods by which a lake can gain or lose heat? Some methods may be mentioned merely to be set aside as being too trivial to consider in the present state of our knowledge. Among such methods may be mentioned the mechanical effect of the action of the wind on the surface of the lake, the beating of the waves on the shore, condensation and evaporation at the surface, the heat generated by organisms in the water and by decaying matter. These and others doubtless all have their effects, but these effects must be small.[1] Moreover, they are more or less constant all the year round, and so cannot contribute appreciably to the changes from the cold of winter to the heat of summer and the subsequent cooling of the waters, which present the chief problems in dealing with the temperature conditions of lakes.

The more important factors which require to be dealt with are: (1) the influences of rivers and rain, (2) radiation, (3) conduction, (4) convection, and (5) wind.

(1) **Effect of Rivers and Rain.**—It is difficult to estimate the effect of rivers and streams entering a lake, both because of the rapid changes which the temperature of streams undergoes, and because of the difficulty in determining the bulk of water entering the lake. A shallow stream very quickly heats up when the sun shines upon it and upon the stones which form its bed, while in winter melting snows cool the waters of streams, even in mild weather, nearly to freezing point. In large and deep lakes, such as Loch Ness, rivers have no marked effect on the cycle of changes which takes place. They do, of course, affect the quantity of heat entering or leaving a lake, but they do not leave any distinct trace on the temperature distribution.

The effect of rainfall is also not directly traceable. Rain quiets the waves, and so retards to a small degree the mixing of the surface layers. As a rule, the rain-water is of a higher temperature than the surface-water, and so its direct effect is limited to the surface layers.

Sometimes, however, after rain-storms, or when snows are melting, the rivers entering a loch come down in spate, and their effect is distinctly traceable. Some smaller lakes become transformed into mere enlargements of the streams entering, and there is a wholesale transference of the waters towards the outlets. When it is remembered that lakes of the dimensions of Loch Ness rise sometimes five or even ten feet in a very short period, it will be seen that even in large lakes the effect of rivers and rain is not negligible. The behaviour of lakes during spates gives some information as to what becomes of water entering: if the river-water is of higher temperature than the surface-water, it remains on the surface and spreads over it; but if the river-water is colder than the surface-water, as is sometimes the case, it sinks until it reaches water of like temperature with itself, and there intrudes itself. In this way, during big spates,

[1] See paragraph on freezing of lakes as to effect of rapid evaporation (page 114).

large wedges of water are sometimes found at considerable depths in the neighbourhood of rivers of the same temperature as the river-water. These wedges gradually flatten out and spread themselves between the upper warm water and the colder water below—unless, indeed, the rivers bring down quantities of matter in suspension, which make the water heavy, and carry it, although perhaps warmer than the surface-water, down to considerable depths.

(2) **Radiation.**—Radiation is a source of gain of heat which affects the cycle of temperature changes in a lake more directly than rivers do, but it is a factor which is frequently overestimated. At first sight it may seem that direct insolation is the chief source of gain of heat in a lake, but it is not so. Although the sun's rays may be perceptible to depths of 100 feet or more (the depth being dependent on the nature of the water and the amount of matter in suspension), the heat rays do not penetrate to anything like so great a depth. There is also a large quantity of heat reflected from the surface, especially when the surface is calm and mirror-like. Dufour [1] found in the Lake of Geneva that more than one-half of the radiant energy received at the surface of the lake was directly reflected.

Dr Knott [2] has calculated for the latitude of Edinburgh the solar energy which crosses unit surface in a given time from insolation, and he finds that per square centimetre—

Energy supplied during summer months = 114,840 gram calories.
Energy supplied during winter months = 19,080 „ „

This gives, say, 134,000 gram calories per square centimetre per annum for the solar supply, or for the whole of Loch Ness a supply of $7{\cdot}2 \times 10^{16}$ gram calories. The actual amount of energy stored up in Loch Ness, as calculated from the temperature observations, was $1{\cdot}9 \times 10^{16}$ gram calories,[3] so that about three-quarters of the heat supplied was lost by reflection and radiation from the lake surface, and by the various other methods by which a lake loses heat.

This seems a reasonable result, and it is confirmed by the observations in Loch Garry, from which it appeared that five-sixths of the heat supplied was lost.

Dr Knott's calculations were for the latitude of Edinburgh, but his values are probably correct within the limits of error for Loch Ness and Loch Garry.

It is a natural question to ask to what depth the sun's rays are appreciable. Forel, by means of a black-bulb thermometer, found that at a depth of 1 metre the direct effect of sunshine was

[1] See Forel, *Le Léman*, vol. ii. p. 333, 1895.
[2] See *Proc. Roy. Soc. Edin.*, vol. xxiii. p. 296, 1901.
[3] See page 134.

considerable, but he does not seem to have carried his observations to any greater depth. In Loch Ness, by means of an electrical sunshine receiver used with the Callendar recorder, the sun's rays could hardly be detected at a depth of 15 feet, though they were quite appreciable at a depth of 10 feet. At a depth of 5 feet it was impossible to distinguish between the effect of sunshine and cloud. Attempts were also made to detect radiation from the loch during the night, but they were unsuccessful.

The observations show that the direct effect of the sun's rays is not appreciable to any great depth, and that they do not directly cause the temperature changes which occur and are appreciable even at the bottom of the deepest lakes.[1]

In the shallow water round the shores of a lake, especially where the shores are shallow and shelving, the effect of the sun's rays is more appreciable than in deep water, as the stones lying on the shore and in the shallow water are heated up, and consequently it is a common experience to find the shore waters of a much higher temperature than the water in the centre of the lake. For a similar reason water which contains a large amount of matter in suspension will gain more heat through radiation than water which is relatively purer.

(3) **Conduction.**—There is a certain amount of heat gained by conduction from the atmosphere—in fact, this is considered by Richter[2] to be the main source of gain or loss of heat by fresh-water lakes. The coefficient of conduction of water is 0·074, while that of mercury is 0·91. It is thus seen that *propagation* of heat by conduction is extremely slow. But through the action of wind, etc., the water heated up at the surface by conduction or otherwise is quickly mixed with colder water, so that there is frequently a considerable difference between the temperature of the water at the surface and the temperature of the atmosphere, favouring a transference of heat by conduction.

There is also a gain of heat through conduction from the earth which forms the basin of the lake, but this is an almost negligible factor; it has been calculated that the heat supplied from this source would only be sufficient to raise the temperature of a layer of water 8 inches thick about 1° Fahr. in a year.

[1] See also page 110. See Fitzgerald, *Roy. Dublin Soc. Proc.*, vol. v. pp. 169–170, 1886. He made some observations in Lough Derg (Ireland) in sunny weather, and from a calculation of the amount of heat entering the water he thought that only about one-fiftieth or less was used in heating it, the rest being probably spent in evaporation. He does not state how his calculations were made, but it is probable that he neglected the effect of wind and convection currents in reducing the temperature gradient at the surface.

[2] See "Seestudien," *Geogr. Abhandl.*, Bd. vi. p. 121, Wien, 1897.

(4) **Convection.** — Radiation and conduction are the principal ultimate sources of gain or loss of heat. Currents produced by convection and by wind are the principal causes of the temperature distribution found in lakes. In spring and summer, when the surface-water is being rapidly heated up, there forms at the surface a layer of water of much higher temperature than the layers immediately below it, and convection currents are set up which equalise the temperature near the surface. I have observed at Dores, on Loch Ness, in perfectly calm weather and out of reach of river influences, the surface temperature to change as much as 6° Fahr. in two minutes. Again, in calm frosty weather there is a similar action of convection currents, the surface-water is rapidly cooled down, and the resulting difference of temperature between the water at the surface and the lower layers is equalised or minimised by convection currents. These currents were clearly demonstrated by the electrical recorder used on Loch Ness. Even the cooling which takes place in the course of cold spring evenings is followed by rapid convection currents, which were at times shown in a startling manner by the recorder.

Convection currents are, however, not limited to the surface. When the discontinuity layer (see page 117) and the temperature seiche are in evidence, there are convection currents set up in the neighbourhood of the discontinuity. It is inevitable that there should be such currents where there are two layers of water of widely different temperatures in contact, especially as the temperature seiche and wind currents cause relative motion between the two layers.

(5) **Wind.**—The effect of wind in determining the temperature changes in lakes has never, I think, been given its due place. To the effect of winds more than to any other thing I attribute not only the cycle of changes which occurs in a lake, but also the absolute quantity of heat which becomes stored up in it. If one could imagine a lake which is never troubled with winds, and the waters of which are ever calm, the problem of its temperature changes would be very easy of solution—there would be no wind currents to carry warm water to its depths and no temperature seiche. There would be no sudden differences in temperature from top to bottom, but a gradual change throughout. The transference of heat from top to bottom would take place almost entirely by conduction, and, as has already been seen, the transference of heat by conduction is very slow.

The detailed examination of the effect of winds will be more conveniently dealt with after an explanation of some of the phenomena which appear. Mention is only made of it at this point for the sake of completeness.

Classification of Lakes

It is customary to divide fresh-water lakes into three classes, depending on the change of density of water with temperature. For convenience of reference the following table gives the density of pure water at intervals from the freezing point up to 70° Fahr., warmer than which it is rare to find water in Scottish lakes :—

Temperature.	Density.
32° Fahr.	0·99987
39	1·00000
45	0·99992
50	0·99973
55	0·99943
60	0·99904
65	0·99857
70	0·99800

It is seen from the table that water has a maximum density point about 39° Fahr., and it is this fact which renders possible the freezing of the surface of lakes. Fresh-water lakes are classed as : (1) those whose waters never fall below 39° Fahr., (2) those whose waters always have a temperature lower than 39° Fahr., and (3) those whose waters are sometimes above and sometimes below 39° Fahr. The names given to these classes respectively—tropical, polar, and temperate—are not very appropriate, suggesting as they do that one class of lakes belongs to the tropics, another to the polar regions, and the third to the temperate zone. This is not so, but the names have now obtained such general recognition that it is not advisable to discard them.

In Scotland there are no lakes of the polar type or class. In a lake of this class the temperature of the water never rises above the maximum density point. As a consequence of this the coldest water is always at the top, the lower layers having a higher temperature ; at the bottom the water may have a temperature of 39° Fahr., but no higher—otherwise the lake would not be of the polar class. Such lakes can only be found in the polar regions or at great altitudes, and in them the cycle of temperature changes is the reverse of what is found in tropical lakes. It will be explained later how in tropical lakes the temperature of the water is nearly uniform in winter, and how stratification sets in as the summer advances. But in polar lakes it is in summer that a uniform temperature is found throughout the lake. As winter draws on the lake becomes thermally stratified, as will be seen by reference to Forel's diagrams (figs. 37–39), which are reproduced by permission. p_0, p_1, p_2 . . . are depth measurements ; the horizontal scale measures time ; m_1, m_2, m_3 . . . n_1, n_2, n_3 . . . are isothermals showing the depth at which the temperatures of m_1, m_2, m_3 . . . n_1, n_2, n_3 . . . are to be found at any period of the year. The isothermal for the maximum density point is represented by a double line. Isothermals for temperatures above this are represented by the lines $m_1, m_2, m_3 \ldots$, and for the temperatures below this by the lines $n_1, n_2, n_3 \ldots$

By far the greater number of Scottish lakes belong to the tem-

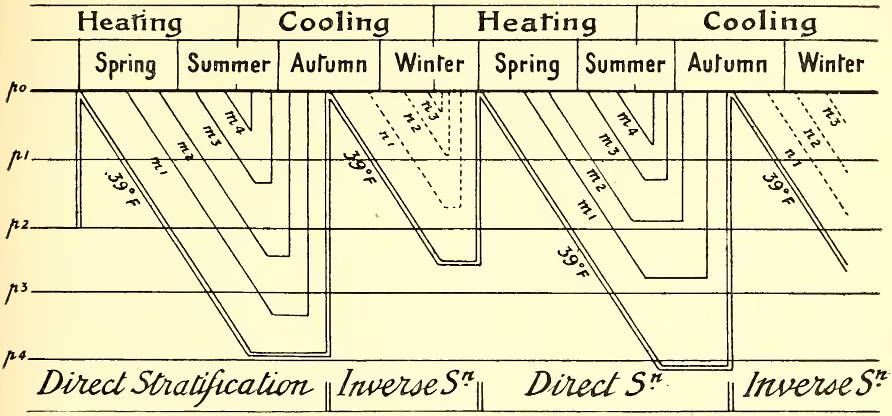


FIG. 37.—Temperate Lakes.

perate class. In summer and autumn the temperature is all above 39° Fahr., the warmest layers of water are at the surface, and the temperature of the water decreases the deeper down it is situated. In winter and spring the water has all become cooled down below the

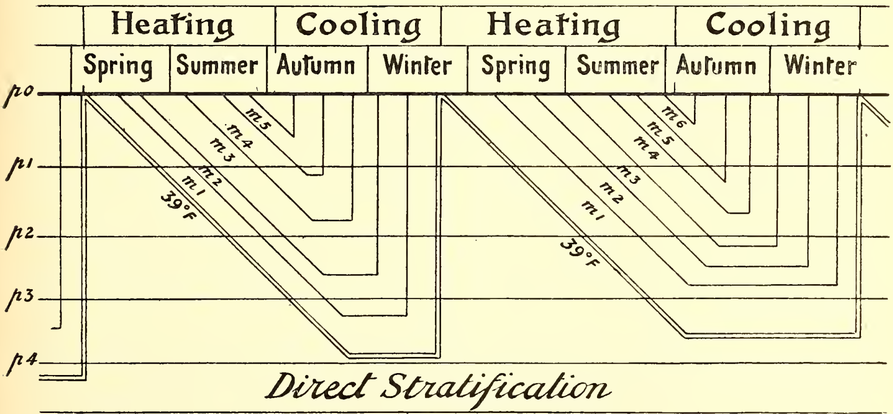


FIG. 38.—Tropical Lakes.

maximum density point, and the condition of the lake is similar to what is found in polar lakes all the year round—the coldest water being at the surface.

The larger and more important of Scottish lakes belong to the tropical class. Owing to their depth the temperature of their waters never falls below the maximum density point. At the bottom the temperature may be 39° Fahr. or higher, and the layers nearer the surface are all of an equal or higher temperature.

A lake may in winter belong apparently to two classes. A series of temperatures taken in a shallow bay will reveal a lake apparently of the temperate or polar type, the colder water being at the sur-

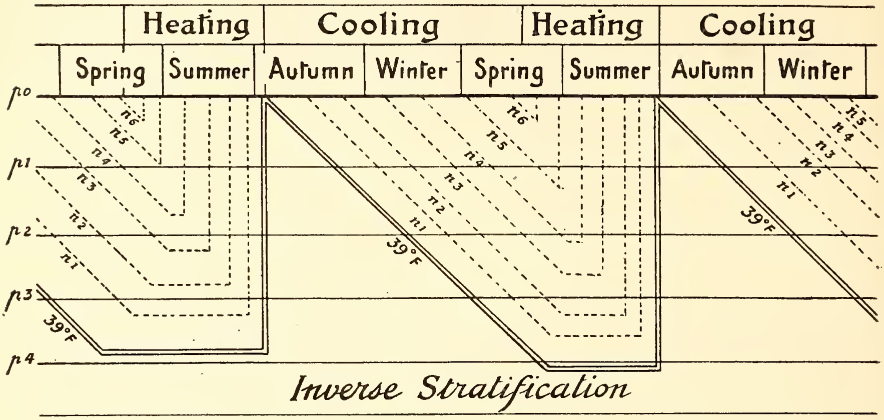


FIG. 39.—Polar Lakes.

face, or the surface may even be covered with ice; while a series of temperatures taken in the deepest portions of the lake will indicate that it belongs to the tropical class—the temperature being all over 39° Fahr. Further reference to this state of affairs will be made when discussing the formation of ice, but an illustration is given in

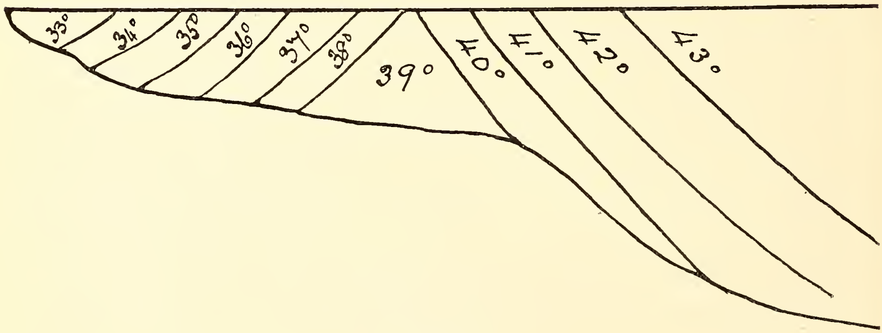


FIG. 40.

fig. 40, which represents the section of part of a lake-basin, and shows temperature distribution where one part of the lake belongs to the temperate class and another part to the tropical class. This diagram is also reproduced from *Le Léman* with Forel's kind permission.

It is the tropical class which is of the greatest interest to the limnologist, as it includes the grandest and largest of our inland waters. It will make what follows more intelligible if the nature of the temperature changes taking place in lakes of this class in the course of the year is briefly indicated. A similar series of changes will take place in temperate lakes during the summer and autumn, for in these seasons distribution of temperature is similar to that found in tropical lakes.

The most convenient starting-point from which to consider the temperature of such lakes is spring, when the water is all of uniform temperature. As summer comes on, the lake gains heat and becomes stratified. This is evidenced by a gradual rise in temperature of the surface layers, the increase being also noticeable at considerable

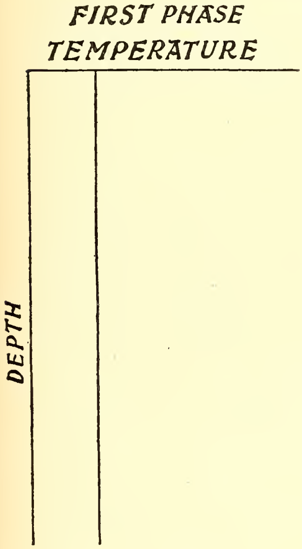


Fig. 41.

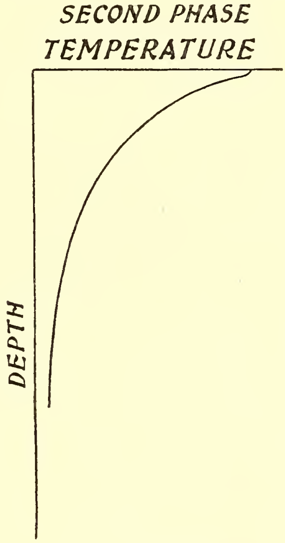


Fig. 42.

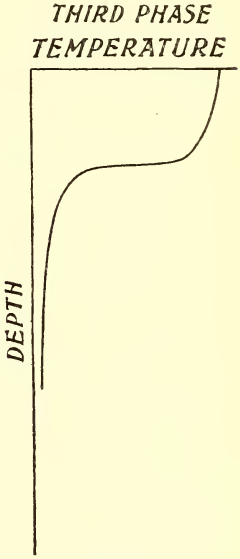


Fig. 43.

depths; the falling off in the rate of increase from the surface to the bottom is very rapid. At the end of summer there is a short period during which there is very little loss or gain of heat, but during which important changes take place. Figs. 41 and 42 show the nature of the distribution of temperature in spring and summer. The spring type is represented by a straight line, the lake being of uniform temperature from top to bottom. The summer type is a smoothly curved line, showing rapid changes of temperature at the surface and very slow changes at greater depths. Fig. 43 shows the autumn type, when the discontinuity layer (or *Sprungschicht*[1]) has made its appearance. There is at the surface a layer of water, say 50 feet in depth,

[1] *Sprungschicht* is the word used by Continental writers. I prefer to use the word "discontinuity," or "discontinuity layer," to describe the nature of the temperature distribution. American writers speak of the "thermocline."

of nearly uniform temperature. Below this there is a layer of water of rapidly varying temperature—the discontinuity layer; and below that again there are the abysmal waters of the lake, also of fairly uniform temperature.

After the lake has become stratified in this fashion, it is, as it were, divided into two compartments separated by the discontinuity layer. As the season progresses, there is a transference of heat from the upper to the lower layer by conduction, convection, and otherwise, with the result that, while the upper layer is falling in temperature by parting with its heat by way of the surface, it is also parting with some of its heat to the lower layer, which goes on rising in temperature, even though the lake as a whole is losing heat. The upper layer of uniform temperature increases in depth, the discontinuity layer gradually sinks deeper, and the difference in temperature between the upper and lower layers decreases, until finally the loch is again of uniform temperature from top to bottom.

This is in brief the cycle of changes which takes place in lakes of the tropical class without reference to the effect of winds and currents. In lakes of the polar class there is no room for the great differences of temperature found in tropical lakes—differences which may amount to 20° Fahr. or more. In polar lakes there is only room for a variation of about 7° Fahr.—from freezing point to the maximum density point. In addition to that, at the coldest period of the year, and for a large part of the year, the lake is covered with ice, which prevents the waters being disturbed by wind, and in consequence the distribution from top to bottom is almost wholly influenced by conduction, and the curve representing the change of temperature from top to bottom is logarithmic. In summer there is a general mixing up of the water by wind influences, etc., so that it becomes all of uniform temperature.

In lakes of the temperate class there is a mixture of the polar and tropical classes. In winter and spring the lake behaves as a polar lake, and in summer and autumn as a tropical lake.[1]

[1] An elaboration of Forel's classification was proposed by Mr Whipple, Director of Mount Prospect Laboratory ("Classification of Lakes according to Temperature," *American Naturalist*, 1898, vol. xxxii. p. 25). He divided each of the three classes into three orders according as the bottom temperatures (1) are practically constant at or near the point of maximum density, (2) undergo annual fluctuations but are never very far from the point of maximum density, (3) are seldom very far from the surface temperatures. This subdivision was thought to be important from the point of view of the periods of so-called stagnation and circulation in lakes; but unless the surface of a lake is protected from the action of the wind by a covering of ice, there is no stagnation period, and the subdivision does not appear to be of great interest. (See remarks on circulation of lakes, p. 121.)

Before going on to deal more in detail with the temperature in fresh-water lakes reference may be made in passing to the difference of the conditions in salt lakes. The differences in density which may occur in the same lake owing to varying degrees of salinity produce complications. As an example of the temperature distribution which is possible, reference may be made to the lakes of Austria-Hungary,[1] some of which contain as much as 25 per cent. common salt. In Lake Medve, which has an average depth of 32 feet, the surface temperature during summer varies from 68° to 86° Fahr. Below the surface the temperature *rises* gradually, and at a depth of about 4 feet reaches a maximum of about 133° Fahr., after which it again falls to about 86° Fahr. at a depth of 18 feet. Other lakes show similarly a median zone of water of high temperature, and the point of maximum temperature is also found to be the point of maximum salinity.

Surface Temperatures

As it is through the surface that a lake gains and loses its greatest quantity of heat, the investigation of surface temperatures is always of importance, although it is not so interesting as the investigation of abysmal temperatures.

The observation of the temperature of the surface is, of course, easier than the observation of the temperature of deep water, as an ordinary mercury thermometer may be used. As a rule, when observing surface temperatures the reversing thermometer was used and immersed in the water at the surface. In this way it is not actually the temperature of the uppermost layer of water which is measured, but a sort of average of the temperature of the first 9 or 12 inches of water at the surface. The observation of the temperature of a thin film at the surface would be a matter of considerable difficulty, even on perfectly calm days, and I am not aware that anything has been done in this direction.

In calm weather a diurnal variation in the temperature at the surface can be distinctly traced; but when there is a wind blowing, this diurnal variation is masked by the changes produced by the wind. Forel had at his command a great number of observations made in the Lake of Geneva, and by taking the means of morning and evening observations he found that the average diurnal variation was about 2°·5 Fahr., the maximum variation being about 8° Fahr. He

[1] See Professor Kaleczinsky, *Scott. Geogr. Mag.*, vol. xviii. p. 317, 1902, and vol. xx. p. 216, 1904. Professor Kaleczinsky suggests that deposits of rock-salt will take place more rapidly in winter than in summer because of the reduced temperature of the water, and that deposits during summer will chiefly consist of anhydrite. The stratification of the deposits thus indicates their age.

also states that the water at the surface to a depth of 2 or 3 feet is of nearly uniform temperature. This is true after passing the first thin surface layer, but I believe the thin surface film, the temperature of which is so difficult to measure, undergoes much greater variation than Forel indicates. There is often at the surface a very steep temperature gradient, and this is never better shown than when there is a thin covering of ice forming at the surface, showing the surface temperature to be very nearly 32° Fahr., whilst the reading obtained by a mercury thermometer, the bulb of which is immersed an inch or so below the surface, is seldom lower than 34° or 35° Fahr.

The extent of the diurnal variation is greatly dependent on the size of the surface waves and the strength of the wind, so that observations on different days are not comparable with one another. Another point, however, is of more importance than this, and that is the depth to which direct insolation—direct heating by the sun's rays—takes place. Rightly or wrongly, I distrust all deductions made by Richter and others as to the depth to which heating takes place by direct radiation. Convection and conduction currents determine the depth to which heating takes place, and these currents are dependent on other factors than the strength of the sun's rays and the angle at which they meet the surface. Only two factors need be mentioned—(1) the effect of wind and the action of the waves, to which I shall return; and (2) the composition of the water and the quantity of matter in suspension, upon which the transparency of water depends. The diathermancy of water is small, and the heat rays are largely absorbed after passing through the first few millimetres of water, so that radiation into a loch is not appreciable at considerable depths; and radiation out of a loch during the night is even slower, for Soret found that the diathermancy of water was less for dark rays than for light rays. In Melloni's[1] experiments on the diathermancy of liquids it was found that, when the source of heat was an Argand lamp with glass chimney, only 11 per cent. of the rays was transmitted through a layer of distilled water 9·21 mm. thick.

Attempts have been made to measure the depth to which direct radiation is appreciable. Forel observed in the Lake of Geneva, by immersing a thermometer with blackened bulb at varying depths, that in midsummer at a depth of 1 metre the black-bulb thermometer read as much as 15° Fahr. higher than the ordinary thermometer. Interesting observations were also made in Loch Ness by means of the Callendar recorder, which was at times used to measure the difference in resistance between a bright and a blackened platinum wire immersed at various depths. When this bolometer was immersed at greater depths than 5 feet it was impossible to distinguish between

[1] *Annal. Chimie et Physique*, sér. 2, t. liii. p. 5, 1833; t. lv. p. 337, 1834.

sunshine and cloud; but to a depth of about 15 feet it was possible to distinguish between night and day by means of the records obtained. With the bolometer in air the deflection shown on the scale of the recorder was 150 times as great as when the bolometer was immersed at a depth of 10 feet.

At first sight these observations in the Lake of Geneva and in Loch Ness seem irreconcilable, but this is not necessarily so, for the waters of Loch Ness are not so transparent as the waters of the Lake of Geneva, partly due to the composition of the water, and partly, no doubt, due to particles of matter in suspension in the water, which absorb radiant heat. The effect of the sun's rays on the Lake of Geneva will also be greater than on Loch Ness, owing to the lower latitude of the former, but 20 feet may be taken as an upper limit to the depth to which direct radiation is appreciable.

How then is heat propagated to great depths? Convection currents begin whenever the isotherms are not horizontal, and this to a small extent aids the propagation of heat to deeper waters. Conduction also carries the heat gained at the surface from radiation, and from contact with the atmosphere, to the lower layers. Weber estimated the depth to which heat would penetrate into a lake in the course of a year, by conduction solely, at 6 metres. It is thus apparent that if the heating were due to radiation, conduction, and convection alone, the changes in the course of a year would be limited to the first 20 or 30 feet of water; but instead of this, temperature changes can be detected even at the bottom of the deepest lakes.

This is due to some extent to warm waters brought down by rivers, which, if they are rendered heavy by matter in suspension, sink down into, and mix with, the colder waters of the lake. But the chief agency in distributing heat throughout a lake is wind-produced currents, which thoroughly mix the surface water, heated by radiation and conduction, with the rest of the water of the lake, and which bring up from the depths of the lake cold water to be in turn heated at the surface.

Many local variations of the temperature of the surface are noticeable. Owing to the action of winds, the warm water on the surface of a lake is carried to the lee end of the lake, with the result that a greater quantity of warm water is met with at the lee end than at the windward end.

Heating and cooling of water take place more rapidly near the shore than in the deep parts of the lake, because of the greater quantity of matter kept in suspension by the beating of the waves on the shore, and also because the shores themselves absorb radiant heat much more rapidly than the water does, and thus help to heat up the shore waters.

Other local variations are due to the state of the surface of the lake, which in some parts may reflect more heat than in others, and so produce local differences. The inflow of rivers also produces local differences.

Even at one point of the surface there may be rapid changes of temperature, especially in early summer and in autumn, when heating and cooling are most rapid. Some interesting records showing this were obtained in Loch Ness by means of the platinum thermometers. During frosty weather the curves obtained by the recorder were of a much more ragged nature than the curves obtained in mild weather. The embroideries on the curves were caused by small changes of temperature which were probably due to convection currents mixing the water which had been cooled at the surface with the warmer water below.

Towards the end of May 1904 the records of temperature at the surface began to show rapid changes of great amplitude. So erratic did the curves obtained by means of the Callendar recorder appear that they were at first attributed to instrumental errors. But the changes were checked by means of mercury thermometers. It was not possible, either, to attribute the changes to wind, for they occurred on the calmest days. Nor can they have been due to river influences, for they were also observed at Dores, where there is no river entering the loch to make the observations suspicious. On one occasion, in two minutes the surface temperature was found to change as much as 6° Fahr. On another occasion, when there was a quantity of pollen from flowers on the shore suspended in the loch, it was observed from the motion of the particles that different layers of water were moving in different directions, and the surface waters were evidently in a very agitated condition, although the surface of the water was quite calm. These and other observations indicate that, while the lake is gaining in heat, even in calm weather the surface-water to a depth of 5 or 10 feet is constantly being mixed up by convection. Were this not so, large temperature gradients would be observed at the surface, and this is the exception and not the rule.

Formation of Ice

It is only in lakes of the polar and temperate classes that freezing can take place. It must be borne in mind, however, that a lake may not always be in the same class. In a year with a mild winter it might fall to be classified as a tropical lake, while in another year with a severe winter it might come within the class of temperate lakes. Moreover, it does not follow that because a lake is of the temperate or polar class it will become frozen over during the winter. The classification depends solely upon the water reaching its maximum density point; but when that point is reached, the water is in a condition which makes freezing possible. Before that point is reached, water cooled by contact with the air or otherwise is heavier than the water immediately below it, and accordingly it sinks until it is mixed with the water through which it falls, or until it reaches water of equal density. In this way warm water is always brought to the surface, and freezing is practically impossible.

But when the maximum density point has been reached, the water which is cooled at the surface no longer sinks. Its tendency is to remain at the surface, and as the rate of conduction in water is small, freezing will readily take place in water at and below the maximum density point.

It is possible for some of the water in a lake to be above the maximum density point while the remainder is below. Fig. 40 shows the temperature distribution to be found in such a case. There are not many actual observations of such a temperature distribution recorded, but it is a matter of common observation that shallow bays in a lake, which as a whole is very seldom covered with ice, may freeze over readily; and in most cases this means that, while the bulk of the water in the lake is above the maximum density point, there is water round the shores that has been cooled below that point.

As a matter of fact, however, the water in a lake is usually cooled considerably below the maximum density point before freezing takes place. There is usually a lapse of time between the date at which the water in the lake has been cooled to the maximum density point and the date at which the air temperature falls below freezing point. During this time the water in the lake is gradually falling in temperature, and owing to the circulation of the water produced by the wind, the whole body of water contained in the lake, and not merely the surface layer, falls in temperature. Thus Buchanan found that the mean temperature of the water under the ice in Loch Lomond was 34° Fahr., or about 5° below the maximum density point, and in Linlithgow Loch 37° Fahr.

Freezing takes place most readily in calm weather, as the effect of winds and storms is to mix the water cooled at the surface with the water below it. At times the freezing takes place all over the surface of the lake in one night, while at other times it begins at the shores, and the ice gradually creeps in to the centre of the lake. This latter is the manner in which lakes with shallow shores freeze. As previously explained, the water round about shallow shores cools more rapidly than the water in the centre of the lake, and so freezes more readily. When once a fringe of ice has formed round the shores, there are set up convection currents from the shore towards the

8

warmer portions of the lake, and for a time these currents will be vigorous. But when these currents have cooled down the surface of the open water sufficiently, and have slackened in consequence, a portion of the water round about the ice-fringe becomes frozen before it can reach the warmer water in the lake, and when this stage is reached freezing proceeds rapidly.

In many of the Scottish lakes, however, the shores are steep, and freezing takes place over the whole surface at once, without the formation of a shore fringe. Freezing in such lakes usually takes place during a calm night in spring with a sharp frost, and an open sky which favours radiation and evaporation from the lake. The surface is at first covered with a network of ice-crystals, and then by a thin sheet of ice. One fact about this mode of freezing, which at first sight is remarkable, is that lakes that have never had ice on them during winter—that is, say, up to the end of February—may be covered with a sheet of ice in a single night during spring. The reason for this is that in spring there are frequently calm nights with intense frosts—spring frosts, as they are called—which are favourable for the rapid formation of ice. Evaporation is very active, owing to the relative dryness of the atmosphere in spring, and on a clear, dry night a wet surface may be from five to ten degrees lower than a dry one. In addition to this, all through the winter the water in a lake is continually losing heat, and it is in early spring, before heating of the water begins to take place, that its temperature is lowest and freezing takes place most readily. In the spring of 1908 observations were made in Loch Garry, and though at no time was the loch completely covered with ice, on several occasions during March large portions of the surface were covered with ice in a single night—with a thickness of as much as half an inch.

But freezing of this nature does not necessarily take place uniformly over the surface of the lake. Ice forms in irregular patches stretching long arms out into the lake. Sometimes there may be open water at the shores, and ice over the deepest parts of the lake. Frequently ice forms about the mouths of small streams, for the waters entering the lake may be very nearly at freezing point, and will float on the surface of the water in the lake and freeze readily. But this is not enough to account for the irregular formation of ice. Isolated patches occur well out from the shores, and not connected with them at all. This may partly arise because some parts of the lake are more sheltered than others from local breezes, which disturb the surface and produce mixing of the surface layer with the warmer water below, so preventing freezing.

There is another possible explanation of the patchy formation of ice. Everyone who is familiar with the appearance of the surface of sheets of water must have frequently noticed oily patches (*taches d'huile*), which are popularly supposed to herald rain. The origin of these patches is not definitely known—it may be that oily substances are brought down by streams. Many explanations have been put forward, but none are conclusive. Their effect, however, is to produce variations in surface tension which hinder the formation of surface ripples. Schneider,[1] in the Obersee, found that water in one of these oily patches was 2°·3 Fahr. colder than water with ripples on it in the immediate neighbourhood. This was, however, probably accidental, for numerous observations were made in Loch Ness with a view to correlating the appearance of these oily patches with temperature differences, but without result. It is possible that freezing takes place more readily on these oily patches, although Forel[2] and Halbfass[3] are of opinion that their effect is negligible. In forming their opinion, however, they had in view alteration in the rate of evaporation and radiation produced by the oiliness of the surface, and not the fact of the absence of ripples and small waves which mix the surface-waters. If there is less mixing of the surface-water in these oily patches, freezing will take place over them more readily than over the rest of the lake. It was observed in Loch Garry that where ice was melting an oily patch formed on the surface of the water.

Another phenomenon connected with the freezing of lakes may be due to the same cause as the patchy formation of ice. It is a matter of common experience that, when a lake freezes over, there are frequently treacherous places on the ice, portions which remain unfrozen, or only become covered with a relatively thin sheet of ice. Popular theory attributes these to wells sending up a supply of water above freezing point to the surface of the lake. This may be a real explanation in many cases, but it must be remembered that either the force of the spring or well must be very strong and prevent freezing by the currents it produces, or else the water of the spring must be of less density than water at 32°, when it will rise to the surface. This means that the spring water must have a temperature of at least 47°.

Forel has discussed a number of possible explanations,[4] and he favoured the view that the *mauvaises places*, as he called them, were simply portions of water which had been kept open by ducks, swans, and water-fowl when ice was forming on other parts of the lake.

[1] "Der Obersee bei Reval," *Arch. für Biontologie*, Bd. ii., Berlin, 1908.
[2] *Bull. Soc. vaud. Sci. nat.*, t. xxxiv. p. 498, 1898.
[3] *Petermann's Mitt.*, Ergänz. 136, p. 82, 1901.
[4] *Bull. Soc. vaud. Sci. nat.*, t. xxxiv. p. 272, 1898.

In lakes which do not freeze all over, but only round the shore, or in shallow parts, as in Loch Lomond, there is always a circulation of water going on. The water which is cooled at the ice-fringe is carried by convection currents towards the open parts of the lake, its place being taken by warm water rising from the bottom; but when once the whole surface is covered with ice there is no circulation of this sort. Nor is there any circulation produced by winds, as the covering of ice prevents the winds forming any currents in the lake. The only disturbing influence is water brought down by rivers, which during severe frosts is of small quantity and of very low temperature, so that it freezes shortly after entering the lake, and produces thickening of the ice round the river-mouths.

But it is not only in calm weather that ice is formed on a lake. Even when the surface of the lake is disturbed by wind and waves, freezing will take place if the temperature is sufficiently low. I have not myself observed freezing taking place in this manner, and I am therefore indebted to the accounts of other writers. The freezing commences by the formation of isolated flakes or crystals of ice, half an inch in diameter or less. By the action of the waves, all these flakes are kept separate from one another; but by rubbing together the edges are worn off, and the flakes assume a circular form. The small particles worn off by friction between these small pieces gather round their edges, and surround them with a margin or wall of friable ice, which has the effect of making the ice-flakes, or *pancakes*, as they are called, sink deeper in the water. These pancakes gradually increase in thickness by the freezing of the water round them, in the same way as an ordinary sheet of ice increases in thickness, and also increase in diameter by the accession of small floating ice-crystals, until they assume a diameter of as much as three feet, always surrounded by the wall composed of small fragments of ice. It is a result of the mode of formation that the section of these pancakes is more or less elliptical, being thickest at the centre and gradually becoming thinner towards the edges. Whenever the surface of the water becomes calm all the pancakes freeze together, and the surface becomes covered by a continuous, though rough, sheet of ice, and thereafter the lake behaves as one which has frozen over in calm weather, and the ice-sheet gradually grows thicker until a thaw sets in.

If an ice-sheet, formed in calm weather, partially covers the lake, and stormy weather and continued low temperature follow, ice grows to the windward by the accretion of ice-crystals. These form even in disturbed water, and, coming in contact with the edge of the ice, freeze to it. Ice grows to the leeward by the extension of ice-crystals over the water. The result is that the ice to windward is rough and white, while that grown on the other side of the sheet is clear and crystalline.

Much interesting information about the phenomena accompanying the formation of ice is contained in Dr von Cholnoky's "Das Eis Balatonsees,"[1] to which reference is made. Lake Balaton is pre-eminently suitable for a study of ice-formation, as its shallowness makes it respond readily to variations in atmospheric temperature. During the winter of 1892–3 the ice attained a thickness of about 18 inches.

The Discontinuity Layer

The general character of the discontinuity layer has already been described, but without reference to its cause. Both in Loch Garry and in Loch Ness the growth of the discontinuity was carefully observed, and it was found that whenever the atmospheric conditions were such that there was no accession of heat to the lake, there was a tendency for the formation of a layer at the surface of uniform temperature, and a consequent discontinuity at the bottom of this uniform layer. There are two principal causes for the formation of the uniform layer:—(1) Owing to the cooling of the surface-water during cold days and during the night, vertical convection currents arise which equalise the temperature of the water; (2) these vertical currents are not appreciable to any great depth—probably to not more than 10 feet. But the circulation produced by the wind deepens this layer and equalises the temperature to considerable depths.

The time of year at which the discontinuity makes its appearance varies with different lakes. In the great and deep tropical lakes, such as Loch Ness, it does not appear so early as in small lakes of the temperate class, for in these small lakes the surface temperature rises much more rapidly than in large lakes, and in consequence the time at which the lake ceases to gain heat arrives sooner than in large lakes. Thus in Loch Garry the discontinuity was distinct in July, and even in June, whereas in Loch Ness it was not distinct till about a month later. Varying seasons must also be taken into account with regard to the period at which the discontinuity appears.

The growth of the discontinuity in Loch Garry at a depth of from 50 to 75 feet is shown by the following observations, made in June, at a time when, owing to dull and cold weather, the rate of increase of heat in the loch was arrested, and there was an actual decrease:—

[1] *Resultate der wissenschaftlichen Erforschung des Balatonsees*, Bd. i. Th. 5, sec. iv.

Observations at Centre of Loch Garry, June 1908.

Depth.	6th.	8th.	9th.	10th.	11th.	12th.	13th.	15th.	16th.	17th.	18th.	19th.	20th.
Surface	56·8	52·2	53·1	52·8	52·8	52·0	51·9	51·8	51·4	51·9	52·0	52·2	52·0
25 feet	50·5	51·5	50·0	52·0	51·9	52·0	51·8	51·5	51·2	51·3	51·1	51·4	51·5
50 ,,	48 0	50·9	48·9	48·7	49·0	50·4	51·0	51·3	51·1	51·0	50·5	50·5	50·9
75 ,,	47·0	49 0	47·0	47·0	46·7	47·0	46·8	46·7	47·6	47·0	47·6	47·5	47·3
100 ,,	46·0	45·9	46 4	46·2	46·2	46·4	46·3	46·3	46·0	46·3	46·2	46·4	46·2
150 ,,	45·8	45·7	45·9	46·0	46·0	46·0	46·0	46·0	46·0	46·0	46·0	46·0	46·0
200 ,,	45·5	45·5	45·8	46 0	45·8	45·9	45·9	46·0	46·0	46·0	46·0	46·0	46·0

The discontinuity is not always well marked. Fig. 47 shows a typical distribution of the isotherms in Loch Ness. It is drawn from the observations made on 17th September 1904. The diagram represents a longitudinal section of the lake, the depth scale being much exaggerated in comparison with the horizontal scale. On this diagram isothermal lines are drawn for every two degrees Fahr. This diagram will be referred to later in dealing with the effect of winds, but it is referred to here in order to show that the discontinuity may be very marked at one end of the lake, as shown by the bunching together of the isotherms, and not nearly so marked at the other end. On the date in question there was a fall in temperature through 50 feet of 9°·4 at Dores (at the north-east end of the lake), while at Fort Augustus the greatest rate of fall was 4°·0 in 50 feet—considerably less than half. The temperature gradient was at times very large on Loch Ness, falls of 5° in 25 feet being common, and at times the fall was as great as 8° in 25 feet.

With such rapid temperature gradients, it is not strange that in the neighbourhood of the discontinuity there are rapid changes of temperature. These were well shown by means of the electrical thermometers and recorder. Fig. 44 is a reproduction of one of the records obtained on 18th August 1904, with the platinum thermometer at a depth of 100 feet.[1] Temperature is measured along the abscissa, and time along the ordinate. The embroideries on the curve correspond to variations in temperature up to 2° Fahr.

It may be that more than one discontinuity is formed in a lake. If two discontinuities are formed, the lake is divided into three layers. An example of this was found in the Wolfgangsee, and will be referred to later.

The depth at which the discontinuity is found varies greatly with different lakes. In Loch Ness it first made its appearance at a depth of about 100 feet; but in comparatively shallow lakes the discon-

[1] The temperature scale of the recording thermometer was not accurately determined, but the range of temperature shown on the diagram is about 5° Fahr.

tinuity is of course at much less depths—in 20, 30, or 40 feet, depending on the depth and contour of each individual basin. In

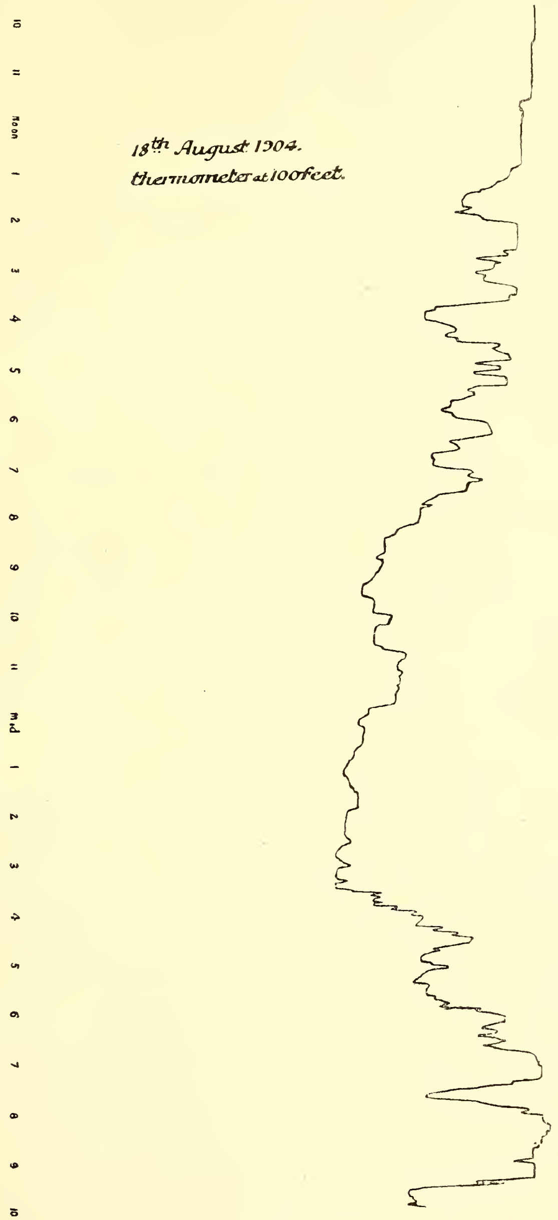


Fig. 44.

Loch Garry the depth at which it first became distinct was about 40 feet.

Stormy weather has the effect of emphasising the discontinuity, and also of increasing the depth at which it is to be found. The thickness of the uniform surface layer gradually increases as the season progresses. The difference in temperature between the upper and lower layer diminishes until eventually the discontinuity of temperature vanishes altogether.

Effect of Winds

The effect of wind in producing currents and in forming the discontinuity layer has been studied experimentally[1] by driving a current of air along the surface of the water contained in a long glass trough. The apparatus consisted of a glass trough 152 cm. long, 10·5 cm. wide, and 12·5 cm. deep, fitted with a parabolic bottom. A continuous blast of air could be driven along the trough by means of an electrically driven rotary fan. The top of the trough was covered over for nearly its whole length, and the trough was as a rule filled to within about two inches of the top. The wind-current was directed along the channel between the cover of the trough and the surface of the water.

It was not found possible to experiment with water of varying temperature. The temperature gradient in a loch (or the rate of change of temperature with depth) is small. If the temperature gradient in the experimental tank were made the same as in a natural basin, very small differences of temperature would require to be experimented with. Where the temperature gradient is made large, conduction and convection currents become of very much greater importance than they are in a natural loch; and as the depth to which the disturbance of surface-waves is felt is relatively much greater in an experimental trough than in a natural basin, the equalising effect of surface disturbances is also much greater. If the gradient in the experimental trough is made comparable to the natural gradient, the range of temperature is very small—so small that the experiments would not have been possible.

The temperature changes occurring in lakes are mainly due to the difference in density of water at various temperatures, and if in experimenting the differences in temperature are very small, the differences in density will be too small to make experiments depending on these differences practicable. The device adopted was that of imitating the differences in temperature by differences in density. In this way it is easy to exaggerate the differences in density which in a lake are due to temperature, and so to make the experiments more manageable, and the effect of conduction is thus eliminated.

[1] See *Proc. Roy. Soc. Edin.*, vol. xxviii. p. 2, 1907.

For the most part, brine solutions were used—a dense solution representing the coldest water in the loch, and water of less salinity representing the warmer and lighter layers.

The results of these experiments may be stated as follows:—

(1) During the period of the year when the differences of temperature in the lake are small, there is a vertical circulation of all the water due to currents of wind, and the return current which supplies water to take the place of water driven along by the wind at the surface is appreciable to the bottom of the lake. This was also thought to be the case from temperature observations in Loch Ness and other lakes, which show that in winter, during stormy weather, the isothermals of the lake may be nearly vertical, necessitating the existence of a current reaching to the bottom of the lake, though probably a very slow one; and indeed the uniformity of temperature in a lake at certain seasons of the year is, I think, sufficient proof that there is a circulation of the water.

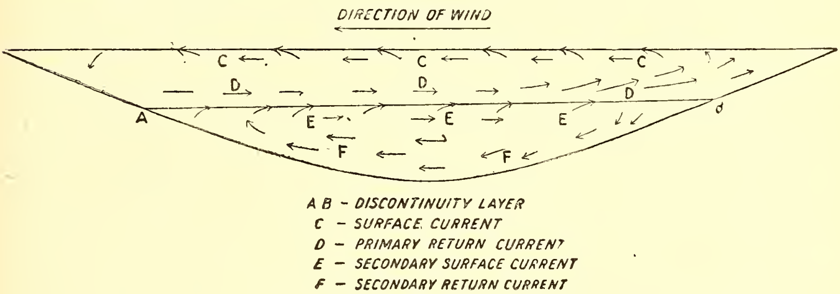


Fig. 45.

(2) When the temperature gradient in a lake becomes marked the density gradient is also marked, and produces its effect on the current systems. It is thought, *a priori*, and from the observations in the experimental tank, that during this period the depth at which the return current is felt grows gradually less as the difference in density increases, and that by the time the discontinuity layer is formed the return current is strongest in the neighbourhood of the discontinuity.

(3) The observations in the experimental tank also indicated that below this return current at the discontinuity, which I call the primary return current, there is a secondary return current in the opposite direction to the primary return current, and induced by it, but in the same direction as the surface current. The system of currents which is thought to exist is shown in fig. 45.[1] Such a secondary return current would necessarily be very slow. Temperature observations

[1] Recently J. W. Sandström has described a similar system of currents in his "Dynamischen Versuchen mit Meerwasser," *Ann. der Hydrographie*, Heft i., 1908.

in Loch Ness, however, made after gales, show considerable distortion of the isotherms at the bottom of the lake, which can only be explained by the existence of currents reaching to the bottom. The observations on 31st August 1903 may be taken for the sake of example. They are shown in fig. 46, which is constructed in the same way as fig. 47, on a diagram representing the south-west half of the lake. For temperatures below 44° Fahr. the isothermals are

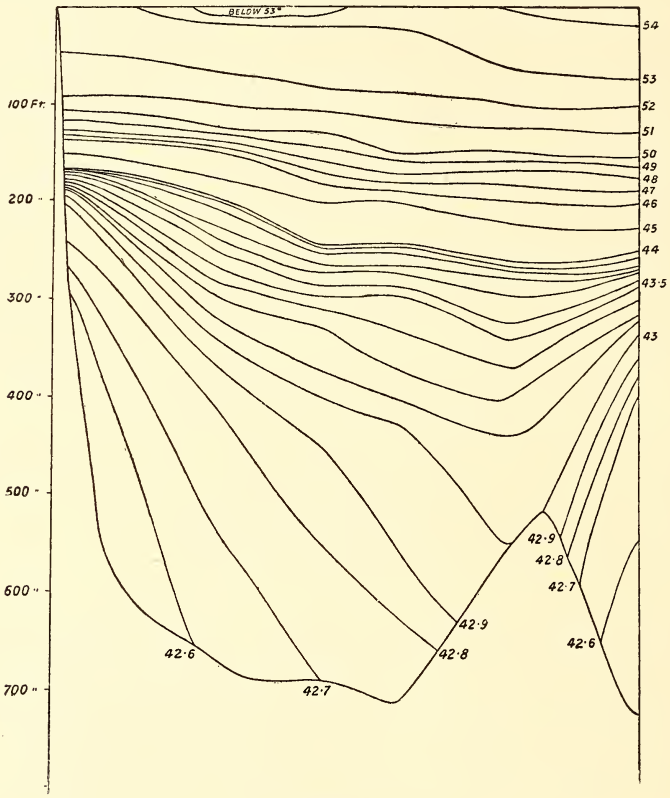


FIG. 46.

drawn for each tenth of a degree; above 44° they are drawn for each degree.

A typical distribution of the isotherms in a lake during autumn is shown in fig. 47. They are bunched together at the end of the lake towards which the wind is blowing, and radiate like a fan towards the opposite end. This distribution can be easily explained on the assumption that the current system is as has been described. The first effect of the wind is the accumulation of a large quantity of warm water at the lee end of the lake, and in consequence the upper isotherms slope downwards from the windward end. The return current along the discontinuity surface has the same effect on the lower layer of water as the wind current has on the surface of the water, and in consequence the lower isotherms slope downwards from the end of the lake from which the return current begins, that is, from the lee end of the lake, and with a slope in a direction opposite to that of the upper layer, producing a fan-like arrangement. In consequence, the discontinuity always appears sharper at the lee end of the lake than at the windward end.

During the year 1908 the author, along with Mr W. Watson, carried out some observations on the currents in Lochs Garry and

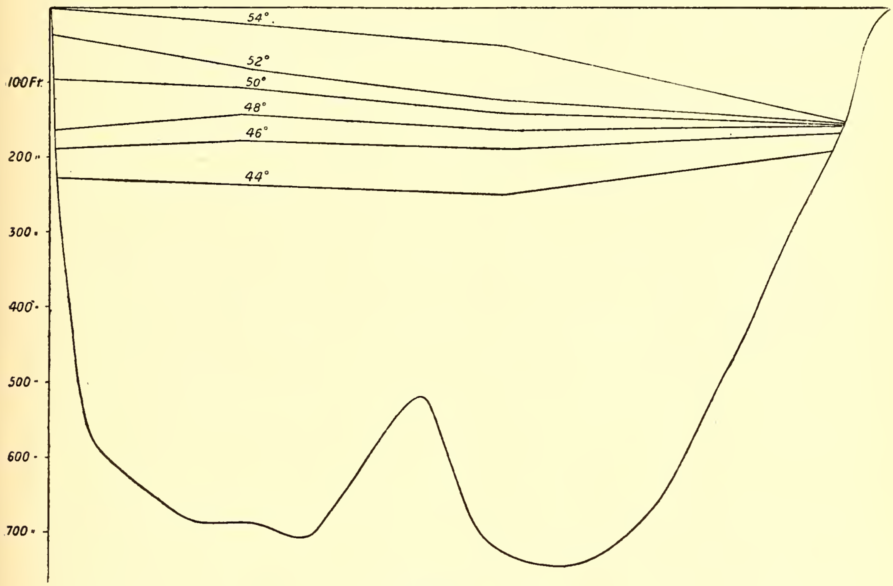


Fig. 47.

Ness by means of Ekman's propeller current-meter. The Loch Garry observations indicate clearly the existence of a return current reaching to the bottom of the lake. Fig. 48 is drawn from observations made on 31st March, when the temperature of the water at the surface was 38°·7 Fahr., and at the bottom 38°·8 Fahr., and shows how the westerly current at the surface, caused directly by the action of a strong west wind, was felt to a depth of about 50 feet, and how below that depth there was an easterly current which within 20 feet of the bottom of the lake had a rate of 3 centimetres per second.

The rate of the current is measured along the abscissa axis, the unit being centimetres per second. The depth of the current is measured along the ordinate axis, the units being feet. The portion of the current to the right of the zero line represents a westerly current, *i.e.* in the same direction as the wind. The portion to the left represents a return current in the opposite direction to the wind.

Observation in Loch Ness was difficult for various reasons, but measurements made in the spring of the year showed very slow currents at depths of from 500 to 600 feet. Numerous observations were also made in Loch Ness after the discontinuity had appeared, and although the results obtained were extremely complicated, it

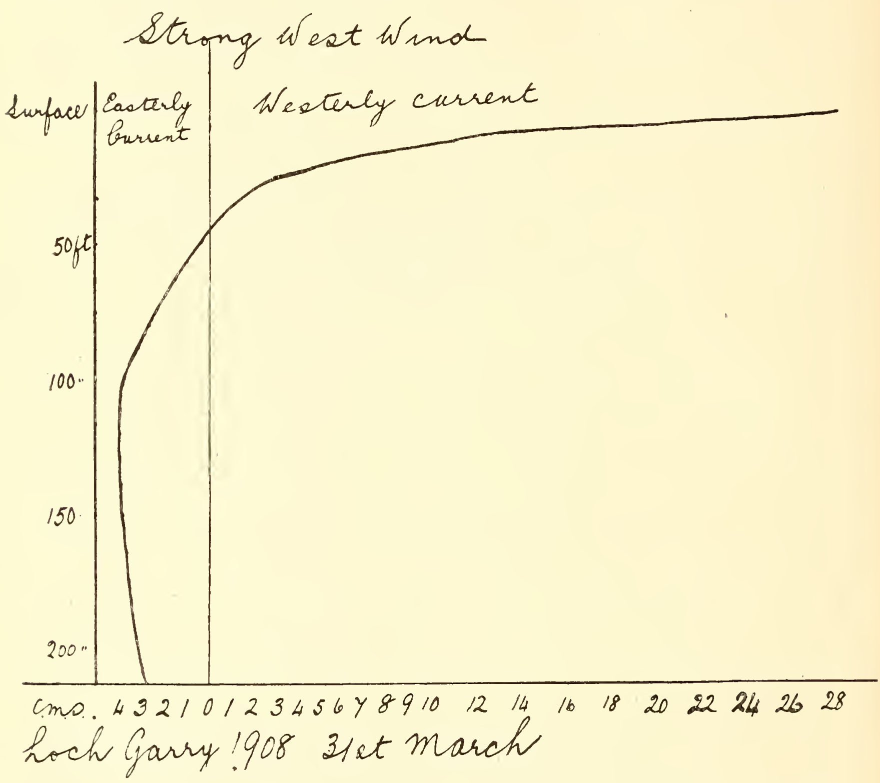


Fig. 48.

appeared that the return current took place above the discontinuity, sometimes very near the surface. It also appeared that the return current was nearer the surface at the windward than at the lee end of the lake, which is natural, as it might be expected that they would follow the direction of the isotherms (see fig. 47).

Below the discontinuity the currents were during the autumn so slow that they could scarcely be detected by means of the current-meter, but as winter progressed they became appreciable to greater and greater depths.

An investigation of the circulation in lakes is important from the biological as well as from the physical point of view, for on the circulation chiefly depends the amount of oxygen available for animal life which is found at the bottom of lakes. The quantity of oxygen at the bottom of a lake should be greatest in early spring, unless the lake has for a considerable period been covered by a sheet of ice. For during winter the whole lake is in circulation, and the whole body of water in the lake may become aerated. At the end of autumn the quantity of oxygen at the bottom of the lake should be at a minimum, as throughout summer and autumn the bottom waters are practically stagnant, and the available oxygen is used up by animal life and decaying matter. In the Lake of Geneva, however, the amount of oxygen at the bottom of the lake at the end of autumn was found to be practically the same as at the surface of the lake, which indicates that absence of life at the bottom of the deeper Scottish lakes must be due not to absence of oxygen but to other causes.[1]

If, however, the lake is frozen over for a considerable period the aeration of the water may not be so perfect, and indeed all the available oxygen in the water may be used up. This was found to be the case in Linlithgow Loch during a severe winter, when eels, which were abundant in the lake, in the search for oxygen forced their way into the drains from the town of Linlithgow in such quantities that the drain-pipes were choked.

The Temperature Seiche

Where two liquids of different densities rest one on the top of the other and do not mix, very slow waves may be propagated in the lower liquid; the most important example of waves of this nature is the "dead water" which is found in salt-water fjords, and in the neighbourhood of melting ice, where fresh water from rivers or from ice runs over the surface of the salt water without mixing with it, and forms a layer of some thickness at the surface. The progress of vessels in such water is at times greatly retarded, owing to the resistance caused to the vessel by its producing very slow waves in the salt water beneath.

Another example of waves produced in the lower of two liquids of different densities is to be found in lakes when the discontinuity is marked between the upper warm water and the lower cold water. At such times it is possible to have a seiche of very long period in the lower layer. In a lake of rectangular section, and where the dis-

[1] See paper by Dr W. A. Caspari, p. 145; Professor E. A. Birge, "The Respiration of an Inland Lake," *Popular Science Monthly*, vol. lxxii. p. 337, 1908.

continuity is abrupt,[1] the period of such a seiche is given by the formula

$$t = \frac{2l}{\sqrt{\frac{g(\rho - \rho')}{\frac{\rho}{h} + \frac{\rho'}{h'}}}}$$

where t is the period of the seiche, l the length of the loch, ρ and ρ' the densities of the cold and warm layers respectively, and h and h' the depths of the cold and warm layers respectively.

But even when the discontinuity is not very abrupt, a temperature seiche may take place. Fig. 49 gives the observations made at Fort Augustus, on Loch Ness, at the surface and at depths of 50, 100, 150, and 200 feet, during July and August 1904. During August observations were made every two hours. Time is measured along the abscissa axis, and temperature along the ordinates. The first curve represents observations made at the surface, the second at 50 feet, the third at 100 feet, the fourth at 150 feet, and the fifth at 200 feet. It will be seen that in the month of July changes in temperature which occur at the surface, due to changes in wind, etc., are traceable to all depths. But in August, when the discontinuity has become marked, the changes at and below 100 feet are independent of the changes at the surface, and have roughly a period of three days. A rough calculation of the period of a temperature seiche from the above formula gives a value for the period of the same order of magnitude. With a view to further test the theory of a temperature seiche, as explaining the oscillation in temperature observed below the discontinuity, observations were made simultaneously at both ends of Loch Ness, and near its centre. The observations at the centre did not show oscillations of a period of three days, but they showed oscillations of a period of about one and a half days, which was probably due to a binodal seiche. The explanation of the absence of the longer-period oscillations is that the observations were made at or near a node. The observations at the two ends of the lake showed a rough opposition in phase, so that little room is left for doubt as to the nature of the oscillations.

It was suggested by Halbfass that the temperature seiche might be peculiar to Loch Ness, or at least to very deep lakes. No observations existed in other lakes sufficient to show the presence or absence of such a seiche,[2] but the observations in Loch Garry in 1908 show that even in a lake with a mean depth of only 78 feet periodic temperature oscillations take place. Fig. 50 gives observations made

[1] See Lamb's *Hydrodynamics*, p. 354.

[2] When making observations in Loch Garry I was not aware of Exner's observations in the Wolfgangsee.

in July 1908, and an oscillation with a period of about twelve hours can be traced. This period also agrees wonderfully with the period calculated from the formula given above.

The amplitude of the oscillation is sometimes enormous. In Loch Ness an amplitude of nearly 200 feet was observed in August 1904,

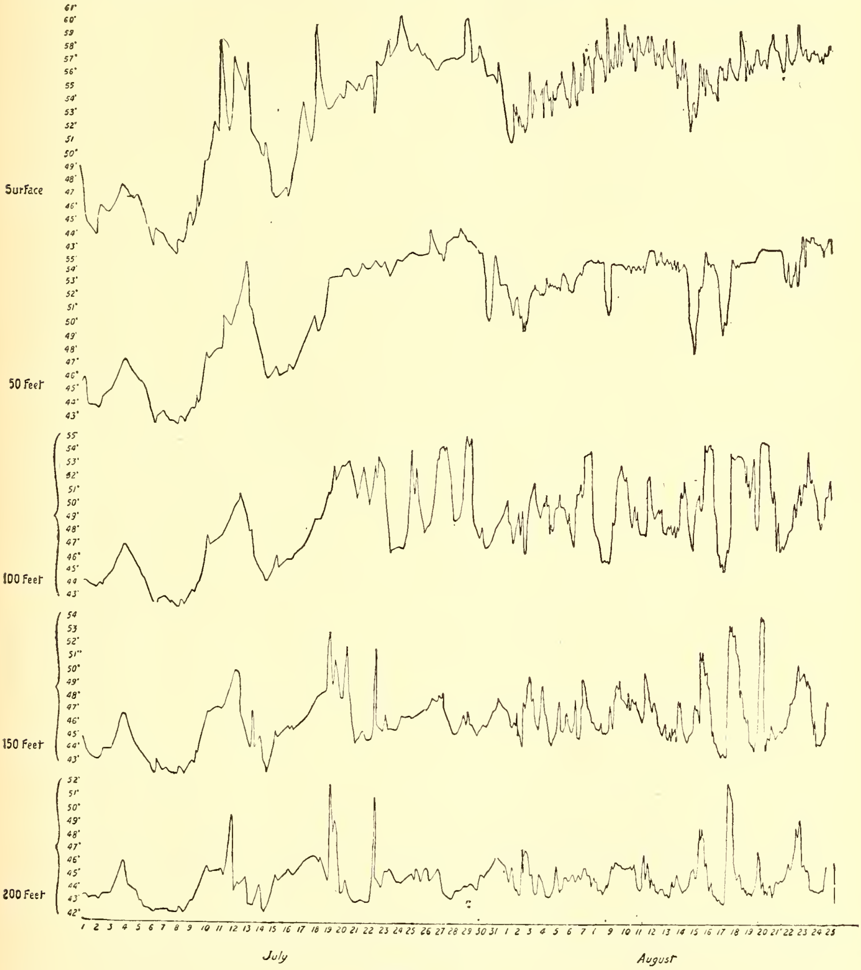


Fig. 49.

which is, of course, far greater than any amplitude which could occur in an ordinary seiche.

The period of the temperature seiche, as will be seen from the formula, varies according to the difference in temperature and the depths of the upper and lower layers. As the autumn progresses the difference in temperature between the layers diminishes, the depth of the upper layer increases, and the depth of the lower layer decreases.

The effect of all this is to increase the period of the seiche; and in Loch Ness the gradual lengthening of the period was detected. Thus, while in August the period was about three days, in November it was found to be between five and six days.

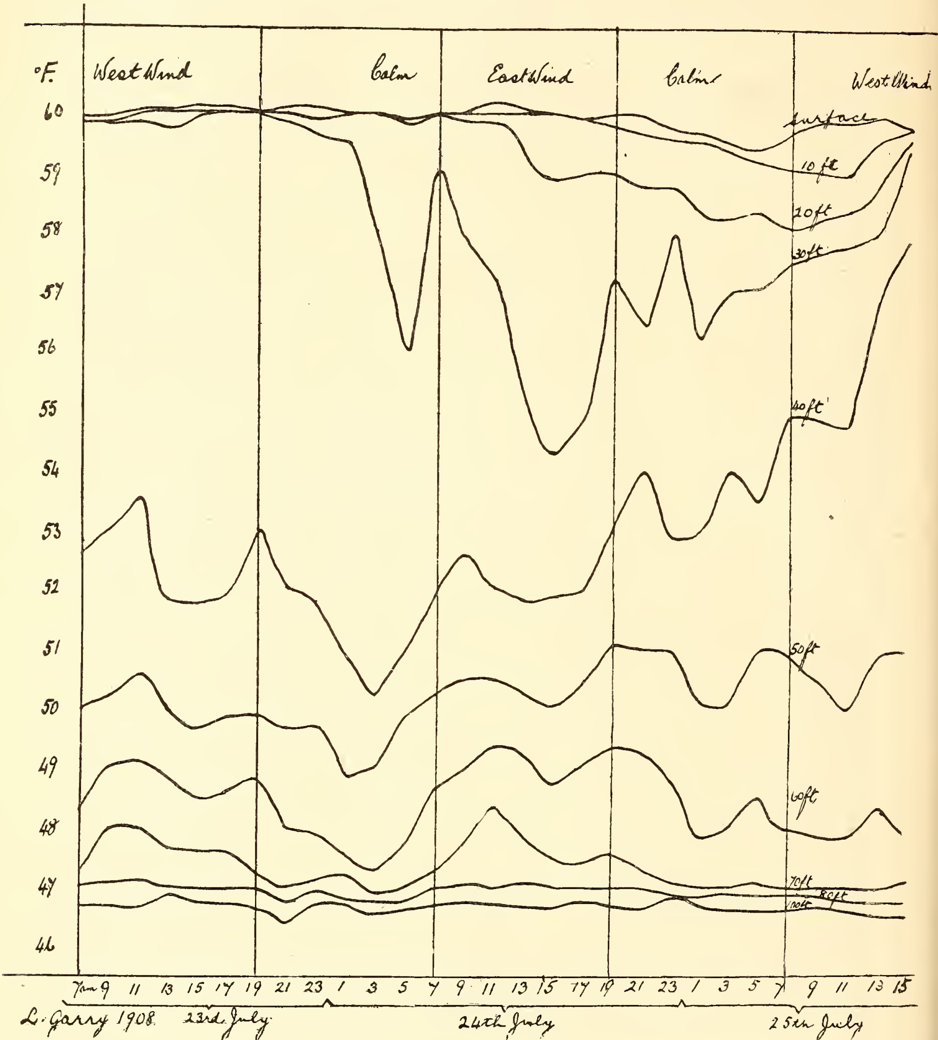


Fig. 50.

Observations of extreme interest were made by Dr Felix M. Exner in the Wolfgangsee in July and August 1907. He worked with six electrical resistance thermometers, which were immersed at the following depths:—

Thermometer No.	I.	II.	III.	IV.	V.	VI.
Feet	2·1	6·2	13·4	23·8	40·0	69·3

The observations were designed to supplement observations made in 1899, on the depth to which the sun's rays penetrate. Owing to a beautiful temperature seiche, which was in progress during the observations, not much light was thrown on this point; but results of greater importance were obtained.

Observations were made at the six depths every three hours, with one or two breaks for repairs to instruments, etc. The observations from 1st to 6th August are shown in fig. 51. Those obtained by means of the first three thermometers show irregular changes of temperature, doubtless due to changes of wind and other causes which directly influence the temperature of the water at the surface. The most remarkable point about these observations is the frequent inversion of temperature that occurs. Some of these irregularities are probably instrumental; but the weather was changeable, and, owing to the high surface temperature, the surface cooling on cold, cloudy days must have been rapid, and may well have caused inversion of temperature.

The observations with thermometer IV., however, at a depth of about 24 feet, show a large temperature seiche, with a period of almost twenty-four hours. The range of the temperature for one oscillation was nearly 14° Fahr. The Wolfgangsee has a maximum depth of 374 feet and a mean depth of 155 feet, and from the experience in Scottish lakes one would not have expected to find a discontinuity at so shallow a depth as to give a temperature seiche at a depth of 24 feet. When Exner's observations were commenced, on 20th July, the surface temperature was only 63°, as compared with about 70° in the beginning of August, and there was not much evidence of a temperature seiche at 24 feet. It is probable that a discontinuity was formed at a shallow depth during the changeable weather which followed the beginning of the observations. There was a discontinuity at about 40 feet when observations were commenced with thermometers V. and VI. on 24th July. This discontinuity was still quite distinct on 1st August, but in addition there was a less marked discontinuity at about 25 feet. The effect is most instructive. The observations with thermometer V. show a temperature seiche of opposite phase to the seiche shown by thermometer IV., and this seiche is also shown by thermometer VI. The reason, as Exner indicates, must be that there was an oscillation of the large body of cold water below, say, 40 feet, and a separate oscillation, of opposite phase, in the layer of water between the upper and lower discontinuity.

It is remarkable that the period of the oscillations should happen to be exactly twenty-four hours, and Exner suggests that the period may be forced by a periodicity in the wind. Such a periodicity would have the effect of producing periodic currents at the surface, and if the natural period of the seiche were sufficiently near the period of the wind, this would be a very effective cause.[1] Taking the depth of the discon-

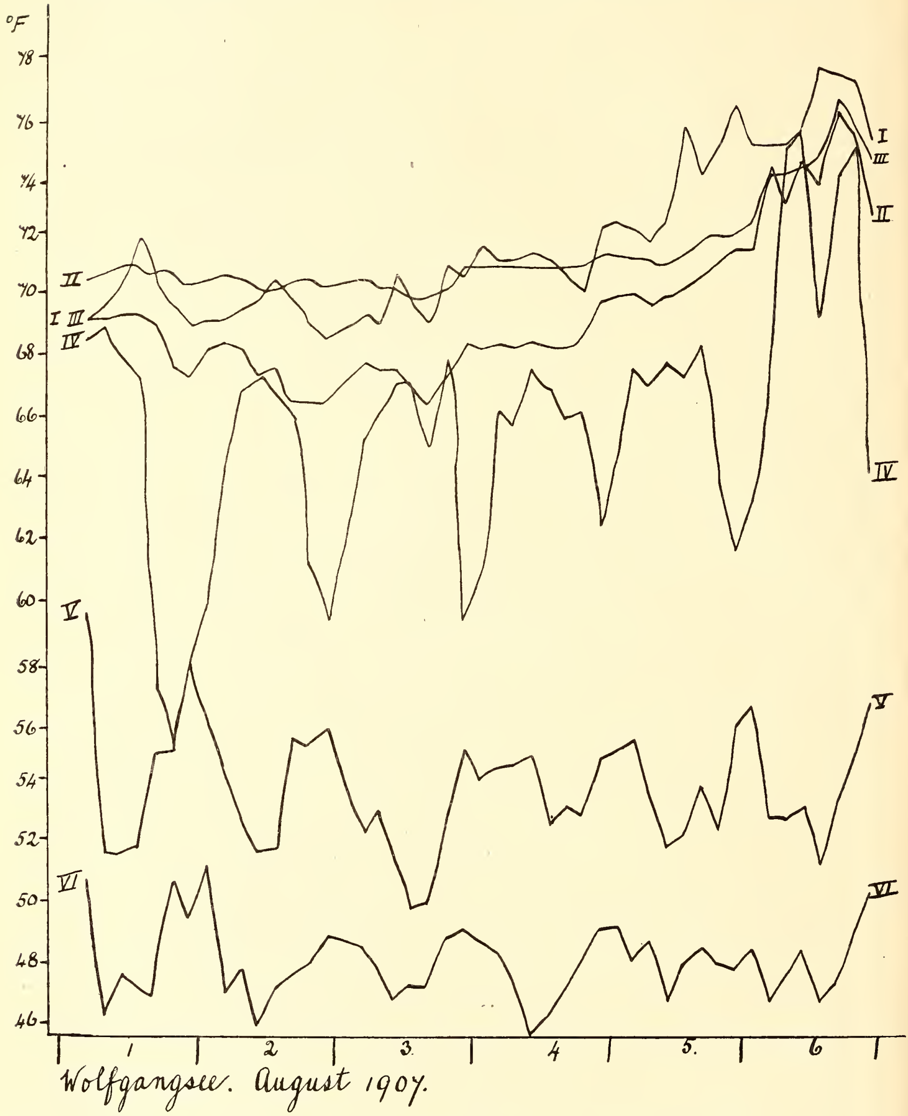


Fig. 51.

tinuity as 24 feet, the length of the lake as 36,000 feet, the mean temperature of the water above and below the discontinuity as 67°

[1] The effect is greatest when the period of the lake is less than the forcing period. See Chrystal on the Seiches of Loch Earn, *Trans. Roy. Soc. Edin.*, vol. xlvi. p. 514, 1908.

and 49° respectively, and the mean depth of water below the discontinuity as 135 feet, an application of the formula on page 126 gives for the period of the temperature seiche twenty hours, which is sufficiently near to the observed period to give colour to the theory of forcing.

Seiches of the amplitude which is observed must produce considerable currents, especially in the neighbourhood of the surface of separation. Assuming that the boundaries of the different layers are sharp, slipping between the layers is necessary, and rough calculations for Loch Ness show that in the case of a temperature seiche with an amplitude of 100 feet (this means that the range of depth at which water of a definite temperature is to be found is 100 feet) the currents due to the motion of the water particles would have a velocity of about 2 or 3 centimetres per second in each layer, or at the surface of separation a relative rate of, say, 5 centimetres per second.

During the experiments in the trough containing liquids of different densities I was able to illustrate experimentally the nature of the temperature seiche. The effect of the wind current at the surface was to accumulate the liquid of lowest density towards the lee end of the trough, and so produce a tilting of the discontinuity layer. When the wind current was stopped or reduced, the surface of discontinuity could be seen to oscillate slowly up and down about the centre of the trough until it came to rest in a horizontal position.

The credit for the discovery of the nature of the temperature seiche belongs to Mr E. R. Watson, B.Sc., at one time a member of the Lake Survey, and now Professor of Chemistry in the Libpur C.E. College, Calcutta; but the discovery was foreshadowed by Professor J. Thoulet in his "Contribution à l'Étude des Lacs des Vosges,"[1] where he says:—"Son eau (*i.e.* Longemer) avait donné naissance, vers 8 mètres de profondeur, à la couche de transition thermique brusque, au sein du lac, et cette couche elle-même, sous l'impulsion de la masse d'eau animée du mouvement dû à son courant et qui lui arrivait à l'une de ses extrémités, s'est mise à osciller longitudinalement et transversalement, comme une sorte de seiche intérieure provoquée par une action mécanique, et l'oscillation s'est communiquée en s'atténuant jusqu'au fond. . . . J'ai tenu cependant à confirmer mon opinion par une expérience synthétique. Dans ce but, j'ai superposé, dans une auge en verre, de l'eau saturée de carbonate de potasse, de l'alcool coloré en rouge et du pétrole. Il m'a suffi de laisser tomber dans le vase des gouttes d'alcool pour communiquer un mouvement ondulatoire synchrone aux trois couches liquides."[2] The Lake Survey observers were at the time of observation ignorant of

[1] See *Bull. Soc. Géogr. Paris*, t. xv. p. 572, 1894.

[2] *Op. cit.*, pp. 31, 32 (sep.).

the work of Thoulet, but it is strange that a period of ten years should have elapsed before any further remark was made on the temperature oscillations in lakes.

Abysmal Temperatures

At the bottom of the deepest of our lakes there is a body of water which varies little in temperature from one year's end to another, and the temperature of this abysmal layer depends largely on the temperature of the preceding winter; but the wind-storms during the year also have a considerable effect in determining abysmal temperatures. In winter all the water in the lake becomes of a uniform temperature, and it is about this temperature that the water at the bottom of the lake remains during the ensuing summer. But the abysmal temperature is not quite constant. Thus, in Loch Morar at 1010 feet, on 29th March 1903, a temperature of 41°·8 Fahr. was observed; while at a depth of 1000 feet, on 23rd October the temperature was 43°·0 Fahr., showing an increase of as much as 1°·2 Fahr. during the year. There is not always so great an increase; thus, in 1887 a number of serial temperatures were taken by Sir John Murray which show a practically constant temperature of 42°·0 Fahr. at great depths throughout the whole year. In Loch Ness, however, the range at a depth of 700 feet both in 1903 and 1904 was from 41°·3 to 42°·6 Fahr.—a range of 1°·3. In Loch Katrine, with a maximum depth of 495 feet, the range of temperature at the bottom is from 3 to 4 degrees. In Loch Garry (Ness basin), with a depth of 213 feet, the range in 1908 was about 10° Fahr.—from 37°·5 to 47°·0.

Sir John Murray has pointed out the influence of winds in varying the abysmal temperatures.[1] Examining the three lochs of the Caledonian Canal, he found that the bottom temperatures varied from year to year, but rose or fell simultaneously in all three lochs. The bottom temperatures in Loch Ness in August and September in eight different seasons are given in the following table:—

Year.	Mean of Observations over 600 feet.	Mean Air Temperature of Previous Winter, November to April.
1877	42°·6 Fahr.	38°·5 Fahr.
1878	42°·4	40°·7
1879	41°·2	34°·0
1880	42°·5	39°·4
1887	42°·4	39°·5
1892	42°·9	38°·2
1903	42°·4	41°·2
1904	42°·3	39°·4

[1] *Scott. Geogr. Mag.*, vol. xiii. p. 1, 1897.

Following the exceptionally severe winter of 1878–79 there is a very low abysmal temperature, but in the other cases the connection between the winter temperature and the abysmal temperature is not apparent. The effect of the wind is more apparent, for in 1877 and 1892, when the bottom temperatures were high, the summer winds were much above the average. These observations indicate clearly that the highest point abysmal temperatures reach during a year depends on the strength of the winds, especially in summer, while the lowest point depends on the winter temperature and also on the strength of the winds during the winter—the stronger the wind in winter the lower the temperature, the stronger the wind in summer the higher the temperature.

The Loch Garry observations were interesting from the point of view of the abysmal temperatures, for it was found that until the formation of the discontinuity the bottom temperature rose by fits and starts following on strong winds.

On 6th May 1908 the temperature at the surface and at 200 feet was respectively 44°·5 and 41°·2, there having been little variation in the bottom temperature during the previous ten days. Owing to stormy weather, no observations were made on the 7th, but on the 8th the bottom temperature had risen to 42°, a rise of 0·8°, showing the influence of currents produced by winds. A more marked case occurred about a week later. On 15th May the surface temperature was 46°·3, and at the bottom the temperature was 42°·3, showing a very slight rise in the bottom temperature. On the 16th and 17th the wind was very strong and no observations could be made, but on the 19th it was found that the bottom temperature had risen 1°·7, to 44°·0. There was a continuance of moderately strong winds, with the result that the bottom temperature had risen to 44°·5 by 22nd May, and to 45°·0 by the 27th. Variable winds were experienced till 5th June, when the bottom temperature was only 45°·2, showing little variation for the previous nine days; but the wind increased on the 5th, and observations on 6th June showed a bottom temperature of 45°·5, and on the 10th 46°·0. Thereafter the winds were light and the weather was cold, with the result that a discontinuity was formed. The bottom temperature remained about 46°·0 until the end of June, and during the month of July there was a gradual and fairly continuous rise, accompanied by moderate and variable winds, to 46°·5. On 6th September, when an isolated observation was made, the temperature at the bottom was 47°·0, showing that the gradual rise in bottom temperature was continued. After the formation of the discontinuity the rise in the bottom temperature was very gradual, and this is explained by the difference in the effect of winds after the discontinuity is formed.

Effect of Lakes on the Climate of Their Surroundings

The temperature of the atmosphere is one of the factors determining the temperature distribution in lakes; but lakes, especially those of considerable size, also have an effect on the temperature of the atmosphere.

In the case of Loch Ness and Loch Garry rough estimates were made of the quantity of heat given out by the lakes during autumn and winter. The estimates were based on a calculation of the maximum and minimum quantities of heat in the lakes in summer and winter respectively, as determined from actual temperature observations. Similar observations were made by Forel in the Lake of Geneva.

The results were as follows:—

Lake.	Total Quantity of Heat set free. Gram Calories $\times 10^{16}$.	Quantity set free per Square Centimetre of Surface. Gram Calories.
Geneva . . .	43·6	75,000
Ness . . .	1·9	34,000
Garry . . .	·1	20,000

The quantity of heat set free per unit area by the Lake of Geneva is very much greater than that set free by Loch Ness, and that set free by Loch Ness is greater than that set free by Loch Garry. It would appear, then, that the larger a lake is, the greater the quantity of heat it is able to set free in autumn and winter, not only as a whole, but per unit surface. The reason of this is probably that in large lakes the period at which heat begins to pass from the lake occurs later than in small lakes, whose temperature rises comparatively rapidly. In them the point at which there is equality between the surface temperature and the average temperature of the atmosphere occurs earlier than in large lakes, and consequently the point up to which the latter gain heat by conduction from the atmosphere is later in the year, and a greater quantity of heat is stored up per unit area.

The difference in latitude between the Lake of Geneva and Loch Ness, and the climatic conditions, also account in part for the difference between the two lakes.

The quantity of heat set free is enormous in the case of the Lake of Geneva. According to Forel, it is equal to the heat set free by the combustion of 54 million tons of coal. A similar calculation for Loch Ness shows that the quantity of heat set free is equal to the heat which would be set free by the combustion of 2·4 million tons of coal—also a very large quantity. Without going into meteorological statistics, it may be stated that the winters along the shores of Loch Ness are so mild that snow never lies on the ground for any length of time. It is also said that potatoes and other root-crops may safely be left in the ground all winter without danger from frost.

There is another method in which lakes influence the temperature of the atmosphere. During the period of freezing there is a considerable quantity of latent heat set free; and again, when the ice-sheet melts in spring, a considerable quantity of heat is absorbed. There is a resulting tendency, in the neighbourhood of lakes which become frozen over, for a spell of frost to be less severe at its commencement, but to be protracted longer than it would otherwise be.

Comparison of Scottish Lakes

Temperature observations were made in nearly all the lakes visited by the Lake Survey, and the observations are given in the descriptive reports. From the fact that the observations were made at widely different periods of the year, and that usually only isolated observations were possible, it is difficult—indeed, I think, impossible—to base a comparison of the lakes, from the point of view of temperature, on these observations. The general factors which enter into and determine the temperature of different lakes have been mentioned in the preceding pages, and in what follows I wish to notice briefly some of the observations in the Scottish lakes which call for special remark.

1. Observations were made in Loch Calder (Forss basin) on 6th October 1902, showing the temperature at the surface to be 51°·4 Fahr., and near the bottom 51°·2—a difference of only 0°·2. The area of the loch is 1·32 square miles, the maximum depth 85 feet, the mean depth 21 feet, and it lies about 205 feet above sea-level. Loch Brora stands 93 feet above sea-level, has a maximum depth of 66 feet, and a mean depth of 23 feet, its area being 0·88 square mile. From these data no great difference in temperature would have been expected between these lakes, but observations made in Loch Brora on 22nd October 1902 showed a surface temperature of 45°·8 Fahr. and a bottom temperature of 45°·0. The temperature gradient is greater than in Loch Calder, and the difference in temperature between the two lakes is surprising, especially as the mean air temperature for October 1902 was about 46°.

2. Loch na Sheallag (Gruinard basin) has a maximum depth of 217 feet, a mean depth of 103 feet, and an area of 1·37 square miles.

Observations made on 14th August 1902 showed a surface temperature of 55°·0 Fahr. and a bottom temperature of 47°·9. Loch na h-Oidhche (Gairloch basin) has a maximum depth of 121 feet, a mean depth of 54 feet, and an area of 0·54 square mile. One would have expected to find a higher bottom temperature in this lake than in Loch na Sheallag, but observations made on 7th August 1902 showed a surface temperature of 51°·0 and a bottom temperature of 46°·8. I am not acquainted with these lochs, and there may be something in their position and surroundings to account for these differences of temperature, but the differences are not *prima facie* easy to explain.

3. Loch Damh (Torridon basin) has an area of 1·32 square miles, a maximum depth of 206 feet, and a mean depth of 59 feet. Temperature observations in this lake on 21st August 1902 showed a temperature at the surface of 56°·5 Fahr.; at 100 feet, 48°·5; and at 200 feet, 42°·2—a temperature usually found in August only at the bottom of the deepest lakes. The simplest explanation, and the one which I favour, is that an error of 5° was made in reading the thermometer, and that the temperature at 200 feet was 47°·2. A mistake of this sort is not uncommon with observers.

4. The observations in Loch Dungeon (Dee basin) are also surprising. In the deepest part of the lake (depth 94 feet) the following temperatures were recorded on 6th August 1903:—surface, 53°·2 Fahr.; 60 feet, 52°·2; 70 feet, 45°·2; 90 feet, 44°·6. If the observations are reliable they show a very marked discontinuity between 60 and 70 feet, and for a lake with a mean depth of only 23 feet the bottom temperatures are very low. The lake is divided into three basins, and this may account for the low temperatures.

5. Loch Muick [Dee (Aberdeen) basin] has an area of 0·85 square mile, a maximum depth of 256 feet, and a mean depth of 116 feet. Compared with its area and length ($2\frac{1}{4}$ miles) Loch Muick is a deep lake, and accordingly there is a considerable range in temperature from top to bottom. Observations were made on 8th July 1905, and gave temperatures as follows:—surface, 56°·1 Fahr.; 50 feet, 47°·2; 100 feet, 44°·3; and 225 feet, 43°·0.

6. Loch Frisa (Mull) may be contrasted with Loch Muick. It has a length of $4\frac{1}{2}$ miles, a maximum depth of 205 feet, and a mean depth of 76 feet. Observations made on 17th August 1904 showed a temperature at the surface of 59°·1 Fahr.; at 50 feet, of 58°·7; and at 175 feet, of 55°·2—11 or 12 degrees higher than at a similar depth in Loch Muick, showing how important a factor is the relation between length and depth. The difference may be partly accounted for by the fact that the observations in these two lakes were made in different years. But a range from top to bottom of only 4° Fahr. in a lake over 200 feet deep is exceptional.

7. One or two examples have been given of very low temperatures in lakes of moderate depth. Loch Shiel is of interest as an example of the converse. Observations taken on 9th July 1902 showed a temperature of 45°·3 Fahr. at a depth of 400 feet, and of 56°·5 at the surface. The length of Loch Shiel is over 17 miles, and the mean depth is 133 feet, so that it is easy to understand this comparatively high temperature.

8. Loch Dubh (nan Uamh basin) has a maximum depth of 153 feet, but has a length of under half a mile, so that the ratio between depth and length is large—1 to 15. This ratio is only equalled by the small loch on Eilean Subhainn in Loch Maree, in which no temperature observations were made. Observations in Loch Dubh on 12th July 1902 showed a bottom temperature of 43°·5 Fahr. and a surface temperature of 59°·0, which contrast sharply with the observations made in Loch Shiel a week earlier.

9. After Loch Dubh, Loch Fender (Tay basin) is the loch with the largest ratio between depth and length. It is only one-third of a mile in length, but has a depth of 78 feet, the ratio being 1 to 22. Observations made on 5th June 1903 showed a surface temperature of 58°·0 Fahr. and a bottom temperature of only 42°·4. The difference between the bottom temperatures of Loch Dubh and of Loch Fender is easily accounted for by the difference in the date of the observations.

10. A contrast is afforded by Lochs Assynt (Inver basin) and Lurgain (Garvie basin), in which observations were made on 16th and 9th September 1902 respectively. Loch Assynt is about 6½ miles long, has a maximum depth of 282 feet, and a mean depth of 101 feet. Loch Lurgain is under 4 miles long, and has a maximum depth of 156 feet and a mean depth of 61 feet. The latter loch is crescent-shaped, so that the force of the wind must be somewhat broken in blowing along its surface. The axis of Loch Assynt, on the other hand, is nearly straight, and the lake has the reputation of being very stormy. This must account for the fact that in Loch Assynt the surface temperature was 53°·7 Fahr. and the bottom temperature 52°·0—a range of 1°·7; while in the smaller and shallower Loch Lurgain the bottom temperature was 50°·3 and the surface temperature 56°·1—a range of 5°·8.

11. In Loch Achilty (Conon basin) observations are available in consecutive years. The loch is 119 feet deep, and only 1500 yards long—a ratio of 1 to 39, so that a low bottom temperature was to be expected; but the range of temperature observed is very large. Observations made on 11th August 1901 showed a temperature at the surface of 63°·5 Fahr., and at 70 feet 42°·3 Fahr.—a range of 21°·2; and on 23rd August 1901 a temperature at the surface of 61°·9 Fahr., at 30 feet 52°·0, and at 60 feet 42°·8—a range of 19°·1. On 21st August 1902 the surface temperature was 58°·4 Fahr., and the temperature

at 100 feet 44°·9—a range of 13°·5. These are remarkable ranges to find so late in the year as the third week of August. Large temperature gradients are common in the beginning of summer, when the bottom waters have not yet become heated up, and when strong sunshine rapidly heats up the surface-water—*e.g.* Loch Monzievaird (Tay basin), in which a range of 20°·6 Fahr. in 36 feet was observed on 8th June 1903. The low temperature of the bottom waters of Loch Achilty is probably due (1) to its comparatively great depth, (2) to its comparatively small drainage area, and (3) to its sheltered position. The month of June (when a lake is most sensitive to winds) was in the year 1901 very free from easterly winds, while in the year 1902 there was a great excess of easterly winds. As Loch Achilty is more exposed to east than to west winds, this may account for the higher bottom temperature observed in 1902.

12. In Loch Glass (Conon basin) a very low bottom temperature of 42°·3 Fahr. was observed on 27th August 1902. The loch is 4 miles in length, with a maximum depth of 365 feet. The axis of the lake runs from north-west to south-east, which is at right angles to the direction of the prevailing winds. It is also slightly crescent-shaped, and it is probable that it does not get the full force of wind-storms.

In order to make a rough classification of the Scottish lakes, I endeavoured to find out which of them had never been known to freeze, or which only froze in very exceptional winters. It will readily be understood that it was frequently difficult, and sometimes impossible, to obtain information about lakes in remote parts of the Highlands, but I owe a debt of gratitude to the many gentlemen who took trouble in giving me information.

The following are the lakes which, so far as I have been able to ascertain, seldom freeze over completely :—

Loch.	Maximum Depth.	Mean Depth.	Remarks.
	Feet.	Feet.	
Morar	1017	284	The deepest of Scottish lakes.
Ness	754	433	Occasionally freezes round shores.
Lomond	623	121	Freezes among the islands in severe frosts.
Lochy	531	229	Shallows at north-east end freeze in very severe winters.
Ericht	512	189	Was nearly, if not wholly, frozen over in 1895.
Tay	508	199	Was nearly frozen over in 1895.
Katrine	495	199	
Rannoch	440	167	Was frozen over in 1895.
Treig	436	201	Three-quarters of the loch were frozen over in 1895, but the tradition is that it had never been frozen over at all previous to that.

Loch.	Maximum Depth.	Mean Depth.	Remarks.
Maree . . .	367	125	Seldom, if ever, completely frozen over (see *Scott. Met. Journ.*, 1908, p. 223).
Glass . . .	365	159	This is one of the lakes referred to above.
Arkaig . . .	359	153	
More (Sutherland) .	316	126	Was frozen all round its shores in 1895.
Awe . . .	307	105	The arm in the Pass of Brander freezes over in severe frosts. The main loch was frozen from Loch Awe Station to within a mile of Portsonachan in 1881. The eastern bay freezes in moderate winters.
Earn . . .	287	138	Is never entirely frozen over. In 1895 it was frozen round the shores.
Assynt . . .	282	101	Was frozen over for about 4 miles from the north-west end in 1895, but the south-east end never freezes over.
Fannich . .	282	109	Was frozen over in 1895. One correspondent informed me that it had a thin coating of ice one morning in March after a severe frost.
Quoich . . .	281	105	Frozen over in 1895, when soundings were made by boring holes in the ice. It has not been frozen since.
Monar . . .	260	98	Frozen over in 1881, 1891, 1895, and nearly so in 1897.
Bhaid Daraich .	121	56	Lies quite close to the sea, and has only been once frozen in the last thirty years, if my informant is correct. In consequence, the lake was supposed to be extremely deep.
Achilty . . .	119	52	Referred to above; was said by one correspondent to have been frozen only once within the last twelve years. Another correspondent informed me that a single night of sharp spring frost was enough to cover it with ice.

It will be seen from the foregoing notes that the information received from various sources was not always consistent, and I cannot, of course, give any guarantee of its accuracy. Among the larger of the lakes about which no information was obtained I may mention Lochs Shiel, Muick, Fada, Suainaval, Sheallag, etc.

Information was obtained as to a number of other lakes, and this information is summarised in the following table :—

Loch.	Maximum Depth.	Mean Depth.	Remarks.
	Feet.	Feet.	
Morie . . .	270	125	Freezes in moderately severe frosts.
Affric . . .	221	94	Bays freeze readily. Whole lake covered with ice in a single night in spring.
Skinaskink . .	216	60	Freezes in very severe winters. Frozen in 1880 and 1895.
Garry (Ness) . .	213	78	Freezes in moderate winters. Covered with ice in a single night in early spring.
Dùn na Seilcheig .	205	85	Seldom frozen except in spring, when it frequently is covered with ice in a single night.
Frisa . . .	205	76	Freezes readily.
Mullardoch . .	197	78	,, ,,
Avich . . .	188	98	Freezes in calm weather. One correspondent states that in December 1907 there was a thin coating over the whole loch for the first time for twelve years.
Bad a' Ghaill .	180	62	Frozen over in 1895. In calm weather considerable portions freeze, but the whole loch does not freeze readily.
Beannachan . .	176	70	Freezes in moderate winters.
Laggan . . .	174	68	Said not to have been frozen completely since 1895.
a' Chroisg . .	168	74	Freezes all over in spring with a moderately severe frost.
Beinn a' Mheadhoin	167	65	Freezes readily.
Luichart . .	164	67	Last frozen in spring of 1903. Does not freeze till spring.
Shin . . .	162	51	Freezes in moderate winters. Frozen in spring of 1907.
Lurgain . .	156	61	Not very often completely frozen over. Freezes readily round edges.
Oich . . .	154	42	Freezes readily.
Owskeich . .	153	47	Thickly coated with ice in 1895. Not completely covered since then.
Lubnaig . .	146	43	Freezes readily.
Bà (Mull) . .	144	47	Freezes in moderate winters.
Ossian . . .	132	43	Freezes readily.
Lungard . .	129	64	,, ,,
Laidon . . .	128	35	,, ,,
Veyatie . .	126	41	,, ,,
Clunie . . .	123	50	,, ,,
Gainmheich . .	120	42	,, ,,

Information was also obtained about a number of smaller lakes all of which froze readily.

Sir Arthur Mitchell, K.C.B., in editing Macfarlane's *Geographical Collections* for the Scottish Text Society, has given interesting notes on Scottish lakes which are reputed not to freeze.

It may be of interest to compare the information given in Macfarlane's *Collections* with later data.

Loch Dùn na Seilcheig, in Inverness-shire, is said never to freeze in winter, but to freeze with a night or two's sharp spring frost. This is curiously similar to information recently received from natives of the district, and is considered reliable.

"Our famous Loch Ness never freezes." The reason has already been explained. Dwellers on the shores of great lakes are as a rule greatly puzzled to account for the fact that the lakes do not freeze, and still more by the fact that water removed from the lakes freezes readily. One boatman, wishing to keep his boat from getting dry while laid up for the winter, filled it with Loch Ness water. The result was not what he anticipated, for the water in the boat froze solid, and burst his boat to pieces.

Samuel Johnson was much interested to hear that Loch Ness never froze, but had hardly a proper appreciation of the cause. "If it be true," he wrote, "that Loch Ness never freezes, it is either sheltered by its high banks from the cold blasts, and exposed to those blasts which have more power to agitate than congeal; or it is kept in perpetual motion by the rush of streams from the rocks that enclose it. Its profundity, though it be such as is represented (140 fathoms), can have little part in this exception, for though deep wells are not frozen, because their water is excluded from the external air, yet where a wide surface is exposed to the full influence of a freezing atmosphere, I know not why the depth should keep it open. Natural Philosophy is now one of the favourite studies of the Scottish Nation, and Loch Ness well deserves to be diligently examined."

Loch Katrine is said never to freeze, and this agrees with reports recently received from the district.

Andrew Symson, writing in 1684 of the White Loch of Myrton (Luce basin), says it is "very famous in many writers who report that it never freezes in the greatest frosts; whether it had that vertue of old I know not, but sure I am it hath not now, for this same year it was so hard frozen that the heaviest carriages might have carried over it." Curling has taken place on the loch on several occasions.

Loch Maree is said never to freeze. The only information obtained at this time was that an old gentleman, who had lived on the shores of Loch Maree for thirty-five years, never saw the loch frozen but on one occasion, very early in the morning, when he fancied a mouse might run across on the film of ice formed from Ardblair to the islands.

"That Intelligent Knight Sir George Mackenzy," in a letter written about the year 1674, makes the following remarks:—"I had notice of a Phenomenon that I judged odd, and considerable searching into the nature of cold, which is,—A little lake in Stratherrick which never freezes all over, even in most vehement frosts, before February, but one night's frost thereafter will freeze it all over, and two nights then will make the ice of a very considerable thickness. This I did inquire after very sollicitously from the honestest and soberest of the adjoining Inhabitants and it was verified by so many that there was left no place to doubt the truth of the matter of fact. I have since heard of two other lakes, one of which is on lands belonging to myself called Loch Monar, of a pretty largeness, which steadily keeps the same method, and I have inquired after it by many who have affirmed it to me on their own knowledge. There is another little Lake in Straglash at Glencarrich on lands belonging to one Chissolm ; the Lake lies in a bottom 'twixt the tops of a very high hill, so that the bottom itself is very high. This Lake never wants Ice on it in the middle, even in the hottest summer, though it thaws near the edges. And this Ice is found on it, though the sun by reason of the reflexion from the hills in that country is very hot, and Lakes lying as high in the neighbourhood have no such Phenomenon. 'Tis observable also, that about the borders of this Lake the Grass keeps a continual verdure, as if it were in a constant Spring and feeds and fattens beasts more in a week than any other grass doth in a fortnight. The matter of fact I have fully examined in both these, but to hit the cause requires a better philosopher than I am."

Loch Monar is referred to above. The loch in Stratherrick is probably the small Loch Scriston, which was not sounded by the Survey. Apparently, however, it is very rarely frozen over. The reference to the lake which is never free from ice even in the hottest summer is of course apocryphal.

Note.—Since the foregoing article was written there have been published two papers which indicate that the temperature observations of the Lake Survey are of considerable importance as throwing light on temperature changes occurring in the ocean. The first of these papers is by Professor Otto Pettersson (*Publications de Circonstance*, No. 47), describing oscillations in the deep water of the Skagerak with a period of fourteen days, which he thinks may be explained as a deep-water tide. The author has tried to show (*Proc. Roy. Soc. Edin.*, vol. xxix. p. 602) that these oscillations may be explained in the same way as the temperature seiche in fresh water. The second paper is by Helland-Hansen and Nansen in the *Report on Norwegian Fishery and Marine Investigations* (vol. ii., 1909, p. 87), where "puzzling waves" are discussed at some length. The authors say: "As far as we can see, it is one of (the) greatest problems (of Oceanography) that most urgently calls for a solution." It seems probable that the explanation of the temperature seiche also applies to them.

The importance of viscosity of water has not hitherto been considered in relation to lake temperatures, but it is a well-established fact that the viscosity of water at 25° C. is only about one-half that of water at 0° C. Biologists have recognised the importance of this in regulating the forms and disposition of plankton animals. It seems likely that this change of viscosity with temperature is equally important in the circulation of lakes. Whenever there is a discontinuity in temperature there is a mobile liquid resting on a relatively viscous liquid. The tendency of this must be to confine wind-produced currents to water above the discontinuity, and so to strengthen the effect of the difference in density between the upper and lower layers of water. The difference in viscosity may, in fact, be as important as the difference in density in determining the circulation.

While we are in the region of speculation, I may be permitted further to suggest that there is an analogy between the temperature seiche in lakes and the movements in the upper air. There again we have two layers of different density one above the other, and the rapid changes in temperature at great heights may be due to causes similar to those which produce large variations of temperature in the neighbourhood of the discontinuity layer in lakes.

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THE CHEMICAL COMPOSITION OF LAKE WATERS

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Comparatively few of the world's lake waters have been submitted to chemical examination. As a rule, only the more highly saline and abnormal waters are analysed for the interest of the thing. Analyses of ordinary waters are seldom undertaken except to test their potability, or with reference to their industrial application; but nearly all potability analyses, and many industrial analyses, are incomplete and of little use to the limnologist. On the whole, however, a fair number of full analyses of lake and river waters have by now been accumulated. Sufficient data being thus at hand, it may here be expedient to review briefly what is known, from the chemical standpoint, about the waters of inland lakes.

In discussing the chemistry of lacustrine waters we have to distinguish sharply between two types of lakes, viz. those which discharge into an outflow, and those which form the terminus of a catchment area. The vast majority of lakes belong to the former type; they are filled with continuously renewed water, and act, as it were, as temporary reservoirs of the system of rivers flowing into them. As regards chemical composition, the water of such a lake will represent an average, or rather an integral, of the waters of its affluents; the additional matter brought into solution from the bed and sides of the lake itself is of vanishing importance, because the area of land acted upon is small (as compared with river conditions) in proportion to the bulk of water, and because there is little or no mechanical erosion in a lake, except within the sphere of wave-action around the shore-line. There is thus no difference in principle between lake water and river water, provided the lake be not a terminus. Ultimately the water of a given lake will depend, for its chemical composition, on the nature of the country traversed by the rivers which feed it.

At all points of its course, a river receives contributions of soluble substances, both through the activity of its own waters and by drainage from the surrounding soil; these substances are derived chiefly from the dissolution of rocks, with or without preliminary chemical decomposition, in which not only water but also carbonic acid and humic acid play a part. The general geochemical effect of flowing waters may be described as the action of a very dilute solution of carbonic acid on the earth's crust, resulting in a continual transference of matter to the ocean. Thus it is impossible for any river to be quite free from dissolved solids; but, on the other hand, the breaking down of rocks into soluble matter is an exceedingly slow process, and is very far indeed from keeping pace with the supply of pure meteoric water. Hence river waters, regarded as solutions, are necessarily of extreme dilution. The formation of anything like concentrated solutions only occurs in enclosed basins, *e.g.* the ocean or terminal lakes, as will be illustrated on a later page. Of the elements found in solution, the foremost are calcium, magnesium, potassium, and sodium, as ranking among the most abundant constituents of the lithosphere; further, sulphur (as sulphates) and chlorine, as being, though less abundant, of highly soluble tendency; whereas silicon, aluminium, and iron, the most abundant elements of all, are but insignificant items, owing to their insoluble tendency.

Wherever there are sedimentary formations, that is, in most parts of the world, there is sure to be calcium carbonate in some form; this substance readily goes into solution, up to certain limits, in water containing carbonic acid, and, though it is very liable to be extruded by other solutes, or by removal of free carbonic acid, is to be regarded on the whole as the principal solute in rivers and fresh-water lakes. The precise form in which the various inorganic constituents exist in solution cannot here be dealt with at length. Broadly speaking, they are present not as definite salts, that is, combinations of an acid and a base, like sodium chloride, magnesium sulphate, etc., but as ions. Basic and acidic constituents, in fact, exist independently in solution, whilst salts as such are practically limited to the solid state. The result is that, if ever two ions, derived originally no matter from what salts, are in solution together to such an extent that the salt combined from them would be supersaturated, that salt is precipitated out of solution as a solid.

The presence of calcium carbonate in a water which otherwise contains only sulphates and chlorides causes the water to show a weak alkaline reaction towards delicate indicators; but it is important to note that, when a water is spoken of as "alkaline," it owes its alkalinity not to calcium but to the alkali metals, sodium and potassium. These latter, when leached out of igneous rocks, are not accompanied by a strong acidic principle (*e.g.* Cl or SO_4)

to balance them, but may be supposed, for the sake of clearness, to go into solution as carbonates; now carbonic is a very weak acid, so that these carbonates behave in solution in much the same way as uncombined bases or hydroxides, and give to the water a decided alkaline reaction, which would grow stronger (whereas alkalinity due to calcium carbonate would disappear) on evaporation. As a matter of fact, both calcium and the alkali metals are in solution as bicarbonate rather than normal carbonate, but it is less confusing for present purposes to think of only the latter as present. Alkaline waters, then, are those which may be regarded as containing a clear excess of sodium or potassium carbonate, and alkalinity can, in most cases, be detected from a statement of analysis if there is more carbonic acid reported than would be equivalent to the amount of lime present.

In addition to these mineral derivatives, many organic substances, originating from the decay of animal and vegetable matter, find their way into inland waters. Little is known as to their nature, and a satisfactory quantitative statement of them is an impossibility; moreover, they tend to be rapidly broken down, chemically and bacterially. Hence, generally speaking, solid organic solutes may be neglected by the physiographer. An exception, however, is to be made in the case of peaty waters. These contain humus, a degradation-product of vegetable matter, which is somewhat resistant to oxidative destruction, and is understood to impart an enhanced solubility to iron (in the ferrous state) and to silica. Dissolved in lake waters, humus has the property of inhibiting some forms of animal and plant life, and there is reason to believe that it aids greatly in the decomposition of minerals. It is a substance of high tinctorial power; hence, notwithstanding the strikingly deep colour of many peaty waters, the organic matter dissolved in them is trifling in actual amount. Peaty waters are very common, indeed predominant, in the Scottish rivers and lakes.

The matter held in solution by rivers varies both in quantity and quality with the geology and climate of the drainage area. In temperate climates the majority of river waters tend to a certain normal composition. They contain seldom more than 0·2 part per thousand of total solids, about one-half of which will consist of calcium carbonate held in solution by free carbonic acid; sulphates come next in order of quantity, followed at some distance by chlorides, whilst magnesium and the alkali metals amount to only a few units per cent. This composition stands in glaring contrast to that of sea-salt, in which we have in descending order of percentages chlorine, sodium, sulphates, magnesium, calcium. Various abnormalities in the dissolved matter of river waters may be brought about by special local conditions of the drainage area: not only may the bulk of solutes be considerably increased, but the proportion of certain single ingredients may be enhanced, as follows:—Sedimentary formations impregnated with sodium chloride (*e.g.* those of marine origin) increase the chlorine; beds of gypsum or pyrites the sulphates (sulphatic waters); peaty lands, owing to the solvent action of humic acids, the iron and silica; igneous rocks the sodium and potassium (alkaline waters); chalk or limestone the calcium carbonate (hard waters). High chlorine contents may also be traced to the near neighbourhood of a sea-board, and to the influence of human life and activity on the drainage area. The effect of local peculiarities is of course much greater on small than on large rivers, which latter represent a summation of many tributary waters.

Rivers flowing through arid countries tend to develop quite another type of water. In the first place, the rainfall is scanty, whence a high percentage of total solids in the river water. Secondly, the scarcity of vegetation results in a dearth of carbonic acid, which is chiefly derived from decaying vegetable matter. Now, calcium carbonate can only exist in solution in presence of free carbonic acid; hence this ingredient dwindles to a minimum. Further, the alkali metals leached out of igneous (felspathic, basaltic, micaceous) rocks attach preferentially carbonic acid to themselves, and form sodium and potassium carbonates, which in turn throw out of solution an equivalent of any other calcium salt, *e.g.* sulphate, which may be present; and the geology of arid regions is frequently of a nature to bring the alkalies into special prominence in the waters. In such waters, therefore, when they are not rendered predominantly chloridic or sulphatic by special local conditions, we commonly find as principal solutes sodium and potassium carbonates, calcium in any form being in a vanishing minority. The waters, in fact, are alkaline, and can be recognised as such by the ordinary litmus test.

It need scarcely be pointed out that the abnormal waters referred to above, whether they be unusually chloridic, sulphatic, or alkaline, are, with regard to the inland waters of the world at large, exceptional. The majority of discharging lakes, then, may be supposed to be filled with a water which holds exceedingly little matter in solution, and that chiefly calcium carbonate. Details may be gathered from the subjoined analyses of lake waters.[1] No apology is offered, or needed, for stating these and subsequent analyses in the modern rational form, according to which constituents present mainly in the ionised state are reported as ions, whilst any carbonic acid present over and above what is required to form *normal* carbonates is suppressed. The item CO_3 in the analyses is not a result of direct deter-

[1] Nearly three hundred analyses of spring, river, and lake waters, mostly American, are quoted, with references, by F. W. Clarke, *Bull. U.S. Geol. Survey*, No. 330, 1908, from which publication several of the analyses here given are extracted.

mination, but is arrived at by difference, and represents the surplus acid required for neutrality after Cl and SO_4 have received their equivalent of bases. Organic matter is left entirely out of account in the analytical statements. Since of all possible combinations calcium carbonate is the one which is nearest its limit of solubility, it is a useful and not wholly misleading convention in interpreting analyses to pair off Ca with CO_3 first of all, any surplus CO_3 being regarded as combined with the alkali metals, and any surplus Ca with SO_4.

		Lake of Geneva (Freundler).[1]	Lake Champlain (Leighton).[2]	Lake Baikal (Schmidt).[3]	Lough Neagh (Hodges).[4]	Loch Baile a' Ghobhainn, Lismore (Tetlow).[5]
Dissolved matter : Parts per thousand.		0·169	0·067	0·069	0·155	0·220
Percentage composition of dissolved matter.	Ca	27·8	21·2	23·4	17·7	38·5
	Mg	4·0	4·2	3·5	1·3	0·2
	Na	1·2	8·8	5·8	15·4	0·3
	K	0·9	...	3·4	...	0·4
	CO_3	37·3	45·8	49·8	36·9	58·2
	Cl	0·6	1·8	2·4	5·7	0·9
	SO_4	25·7	11·0	6·9	10·7	trace
	SiO_2	2·5	5·6	2·0	3·3	1·2
	$(AlFe)_2O_3$	trace	1·6	1·4	6·7	0·3

The first three are examples of more or less normal waters, that of the Lake of Geneva having a somewhat sulphatic tendency. In Lough Neagh there is excess of chlorine and of iron, due respectively to wind-blown salt from the sea, and to the passage of its affluents through peaty country. This water and those of Lakes Champlain and Baikal are slightly on the alkaline side. The last analysis shows a typical hard water existing in a limestone country: the amount of dissolved matter is large, and it consists almost exclusively of calcium carbonate. As a Scottish loch water this is quite exceptional; the mainland loch waters generally are exceedingly pure; *e.g.* both for Loch Ness and Loch Katrine[6] 0·029 part per thousand of total solids (organic included) are reported. Even purer are the Lake District waters, *e.g.* Thirlmere, with 0·020 part per thousand.

[1] Forel, *Le Léman*, ii. p. 581, 1895.

[2] U.S. Geol. Survey, *Water Supply Paper* 121, 1905.

[3] *Bull. Acad. St Petersburg*, xxiv. p. 423, 1878.

[4] *Chem. News*, xxx. p. 103, 1874.

[5] *Proc. Roy. Soc. Edin.*, xxv. p. 970, 1905.

[6] From an analysis of this notoriously soft water, kindly supplied by Mr F. W. Harris, City Analyst of Glasgow, it appears that carbonates are almost or entirely absent, whilst sulphates preponderate somewhat over chlorides; calcium makes up 12 per cent. of the solids, and magnesium is reported in traces only.

Turning now to lakes not furnished with outlets, we meet with a variety of waters which contain relatively high proportions of dissolved matter, and show great eccentricities in their chemical composition. Ordinary lakes are merely temporary storehouses of the soluble substances extracted from the surrounding land on their way to the sea. Terminal lakes, on the other hand, usurp the function of the sea itself as the final repository of these substances. In such lakes the loss of water by evaporation is *ipso facto* equal to, or greater than, the supply from affluents and rainfall. Consequently all the dissolved matter of inflowing rivers is gradually accumulated in the lake water, and, generally speaking, the older the lake, the more highly charged its waters will be. The total solids may thus rise to hundreds of parts per thousand.

Profound alterations in the nature of the dissolved matter are involved by this process of concentration. In the first place, the predominant calcium carbonate of river waters is present only by virtue of free carbon dioxide in solution. Now this latter must remain approximately in equilibrium with the carbon dioxide of the atmosphere, and cannot, therefore, accumulate to any extent: on the contrary, it tends to be ousted more and more as the water increases in salinity. The result is that calcium carbonate must be eliminated, usually by precipitation as calcareous tufa, travertine, or oolite. In exceptional cases the oceanic mode of elimination, viz. by biological agencies, comes into play. The deposition of calcium carbonate begins at an early stage in the history of an enclosed lake, long before any other constituents are separated out. This transference of calcium from the dissolved to the undissolved state is one of the most salient phenomena of terminal lakes and of the ocean, and goes on continuously so long as there is an influx of continental waters.

The further changes which may take place as the concentration of lake water progresses follow from the solubilities of the various possible salts concerned. It will be remembered that any cation can pair off with any anion, so that as soon as the saturation-limit of a salt corresponding to any pair has been transgressed, that salt will begin to separate out. Leaving calcium carbonate on one side, we find that calcium sulphate would be the first salt to pass out of solution as gypsum or anhydrite. This precipitation only occurs at an advanced state of concentration, even when the lacustrine and affluent water is of the normal type. When the inflowing waters contain a slight excess of alkali, existing as sodium and potassium carbonates, calcium carbonate is thrown down by double decomposition, and the separation of calcium sulphate is to a corresponding extent averted, whilst soluble sulphates accumulate in the water.

When the total solids have passed beyond 20 per cent., sodium sulphate or carbonate, or magnesium sulphate, may crystallise out, according to the composition of the solutes and the temperature. The proviso as to temperature is necessary, because the solubility of sodium sulphate increases in an exceptional degree with temperature; in fact, there are waters which are unsaturated for this salt in summer and deposit it in winter. Beyond 30 per cent., sodium chloride begins to separate out. Magnesium chloride remains in solution to a point not far short of actual desiccation.[1]

The following analyses of terminal lake waters illustrate the diversity which the composition of such waters can assume, and the great difference between them and river waters :—

		Lake Sarat, Roumania (Carnot).[2]	Lake Van, Armenia (Chancourtois).[3]	Lake Urmi, Persia (Günther[4] and Manley).	Lake Palic, Hungary (Von Hauer).[5]	Great Salt Lake (Waller).[6]	Caspian Sea (Lebedintzeff).[7]	Ocean (Dittmar).[8]
Dissolved matter: Parts per thousand.		58·0	21·0	148·5	2·2	199·2	12·6	35·0
Percentage composition of dissolved matter.	Ca	0·39	...	0·32	0·66	1·0	2·6	1·2
	Mg	2·1	0·57	2·5	3·3	2·1	5·7	3·7
	Na	31·7	37·6	34·0	35·8	32·9	24·5	30·6
	K	...	1·2	0·78	...	1·7	0·60	1·1
	CO_3	0·27	20·7	...	40·9	...	0·93	0·21
	Cl, Br	28·2	27·1	57·3	15·7	55·7	41·8	55·5
	SO_4	37·1	11·9	5·0	2·9	6·5	23·8	7·7
	SiO_2	0·04	0·85	...	0·27	0·01 (SiO₂ and (AlFe)₂O₃ together)	...	...
	$(AlFe)_2O_3$	0·02	trace	...	0·45		...	...

In these lakes deposition of sodium salts has not yet begun, or is at an early stage. Lake Sarat represents a concentrate of normal river waters, Lakes Van and Palic of alkaline waters. In Lake Urmi and Great Salt Lake we see the effect of an elimination of calcium sulphate and find sodium chloride accumulating; both are lakes of very high salinity. It will be observed that the dissolved solids of these two lakes closely simulate those of the ocean in composition; but this is more or less accidental, and is by no means to be regarded

[1] These statements are to be regarded as simplifications. As a matter of fact, the crystallisation of concentrated natural waters is an exceedingly complicated affair, owing to the numerous double salts which can and do separate from solution. The physical chemistry of the subject for the special case of sea-water has been worked out with remarkable thoroughness, and may be referred to in Van't Hoff's *Ozeanische Salzablagerungen* (2 vols., Brunswick, 1905–09).

[2] Bujor, *Ann. Sci. Univ. Jassy*, i. p. 158, 1901.

[3] *Comptes rendus*, xxi. p. 1111, 1845.

[4] *Proc. Roy. Soc.*, lxxv. p. 312, 1899.

[5] *Jahrb. geol. Reichsanstalt*, vii. p. 361, 1901.

[6] J. E. Talmage, "The Great Salt Lake," *Scott. Geogr. Mag.*, xvii. p. 635, 1901.

[7] Karaboghaz Expedition Reports (in Russian), St. Petersburg, 1902.

[8] *Challenger* Reports (*Phys. Chem. Chall. Exp.*, Part I. p. 203), 1884.

as a general tendency. The resemblance is due partly to the disappearance of calcium sulphate from solution, and would not have existed at a period when the lakes were no more concentrated than the ocean; partly also it results, at least in the case of Great Salt Lake, from an inflow of exceptionally chloridic river waters. On the other hand, the Caspian, which actually began life as an arm of the ocean, has become much more sulphatic, being fed largely by alkaline waters. So pronounced is the accumulation of sulphate, that when, in the Karaboghaz Gülf, local concentration of Caspian water takes place, sodium sulphate (Glauber's salt) is thrown down.

We have seen how the early stages in the concentration of lake waters produce, by elimination of calcium, waters in which sodium is the chief metal. When, to go a step further, a lake is so near the end of its career that it has for a long time deposited sodium salts, magnesium becomes predominant. The waters now contain much magnesium chloride and sulphate, and resemble in every way the artificial "bitterns" or mother-liquors which remain when common salt is manufactured by crystallisation out of sea-water. The waters tabulated below are familiar examples of this. The Karaboghaz is merely a gulf of the Caspian Sea, in which large deposits of sodium sulphate and chloride have crystallised out. Lake Elton, an oceanic derelict, has deposited salt and gypsum, and is said to yield a crop of magnesium sulphate in the winter. The Dead Sea is a concentrate of Jordan water, an abnormal river water of which an analysis is adduced for comparison.

		Karaboghaz Gulf (Schmidt).[1]	Lake Elton (Erdmann).[2]	Dead Sea (Terreil).[3]	River Jordan (Anderson).[4]
Dissolved matter: Parts per thousand.		285·0	265·0	259·9	1·61
Percentage composition of dissolved matter.	Ca	...	0·10	6·6	7·9
	Mg	15·8	17·5	15·9	9·5
	Na	11·5	11·3	5·5	15·5
	K	1·8	...	1·7	1·1
	CO_3	...	0·0	trace	12·7
	Cl, Br	53·4	64·2	70·0	49·4
	SO_4	17·4	6·8	0·24	3·6
	SiO_2	...	..	trace	0·15

The final state towards which these waters, which are more or less of the oceanic type, tend is that of a solution of little else than

[1] *Bull. Acad. St. Petersburg*, xxiv. p. 177, 1878.
[2] *Pogg. Ann.*, xxxv. p. 172, 1835.
[3] *Comptes rendus*, lxii. p. 1329, 1866.
[4] *Rep. U.S. Dead Sea Expedition*, p. 202, 1852.

magnesium chloride. But if the waters subjected to concentration are alkaline, the result will be very different. As concentration proceeds the preponderating sodium carbonate tends to throw not only calcium but also magnesium out of solution, and the final liquors will consist almost entirely of sodium salts, viz. carbonate, sulphate, and chloride. In certain rare instances boric acid originating from volcanic vents has found its way into lakes. Its presence in solution seems to be confined to highly saline alkaline lakes, and this may be due to the fact that where calcium and magnesium are present in appreciable quantity, boric acid would tend to be eliminated as insoluble borates; whereas in alkaline concentrates it would persist in solution as borax (sodium pyroborate).

During the world's history many lakes must have dried up completely after accumulating a large store of salts. In moderately humid climates this cannot have happened often, but when it did happen, an inverse process of re-solution must have gradually set in. Thus the saline residues would lose first magnesium and then sodium salts, whilst calcium sulphate and carbonate might well survive into recent geological periods. Rock-salt deposits generally, and especially the sodio-magnesio-potassic deposits of the North German Plain, are monuments of bygone lakes of sea-water, cut off from the ocean; probably, however, these are instances not of desiccation to the last drop, but of copious deposition of salts followed by withdrawal of the mother-liquors. Far less resistance is offered to the formation and survival of saline residues in arid regions; many such, of very variable composition, are known to exist, some of them being exploited commercially, especially in the Nile Valley, Central Asia, and the United States. Since arid regions, as we have seen above, are apt to produce alkaline waters, these deposits consist as a rule largely or mainly of sodium carbonate, occasionally with a considerable proportion of borax.

Of a very different class of solute, which is never absent in lake waters, viz. the dissolved gases, there is but little to be said. Whilst this department of hydrology has received a great deal of attention from oceanographers, experimental data as to the gases dissolved in lakes are, so far, scanty and isolated; and it is to be admitted that the subject bristles with physical and chemical complications, and presents no small experimental difficulties. Pure water in contact with air takes up oxygen, nitrogen, and carbon dioxide up to definite limits of saturation. The amount of each gas taken up is directly proportional to its partial pressure, decreases, though not in a simple relation, with increasing temperature, and lastly depends on a solubility constant which varies somewhat widely from gas to gas. As an effect of their respective solubilities, oxygen and nitrogen go into solution not in their atmospheric ratio (1 : 4) but in the ratio of approximately 1 : 2. When we come to natural waters, we find that high salinity lowers the absolute solubility of gases somewhat, and that carbon dioxide is greatly affected by the chemical affinity for it of dissolved carbonates. With regard to the latter gas, all hitherto published data are untrustworthy as to the amount in solution in the gaseous, as distinct from the ionised, state, and we are not likely to become better informed until a sound experimental method of measuring the *tension* of the gas in solution becomes universal. The saturation-solubilities of oxygen and nitrogen, at partial pressures of $\frac{1}{5}$ atm. and $\frac{4}{5}$ atm. respectively, as in air, are set down in the following table, expressed in c.c. at 0° and 760 mm. per litre of liquid :—

	Oxygen.	Nitrogen.
Pure water at 0° C.	10·29	18·56
,, ,, at 15°	7·22	13·63
,, ,, at 30°	5·57	10·94
Sea-water (salinity = $3\frac{1}{2}$ per cent.) at 0° .	8·36	14·40
,, ,, ,, at 15° .	5·84	11·12
,, ,, ,, at 30° .	4·50	9·26

In the best-explored lake, that of Geneva, a series of experiments showed the content of oxygen to be 6·8–7·6 c.c. per litre, and nitrogen 14·6–15·9 c.c. per litre, at various depths and at temperatures ranging from 4° to 9° C. There was very little variation from the surface down to 300 metres (984 feet), which is doubtless due to the even vertical temperature of the lake and the complete circulation which it consequently enjoys. The amounts of gas dissolved are seen to be rather below saturation in the case of oxygen, and very near saturation in the case of nitrogen. Very different are the waters of the Caspian: in the South Basin 5·6 c.c. of oxygen at 100 metres (328 feet), tailing down to 0·73 c.c. at 715 metres (2345 feet), are recorded ; in the North Basin 2·3 c.c. at 150 metres (492 feet) down to 0·13 c.c. at 575 metres (1886 feet). Here the bottom waters are altogether destitute of oxygen, and there is no animal life below 400 metres (1312 feet). Wherever the bottom waters are inadequately ventilated, reduced sulphur compounds are apt to be generated in the deposits, and this sometimes leads to the presence of an abnormal gas in solution, namely sulphuretted hydrogen.

The quantity of gas held in solution in any part of a lake is governed by a multiplicity of factors. It depends first of all on the circulation of the lake: thus lakes of uniform temperature, especially the shallower ones, are well aërated from top to bottom ; lakes with a discontinuity layer (*Sprungschicht*) receive an ample supply of gas in the upper, and very little in the lower, waters; frozen lakes are cut off from the atmosphere and are gradually depleted of oxygen until thawing sets in. In this connection wide seasonal variations may be expected. In the second place, the gases are much shuffled about by the organic life of the lake waters. Animals and most bacteria consume oxygen and produce carbon dioxide. A defect of oxygen therefore means a scanty fauna, and this may involve important economic consequences, *e.g.* when the bottom waters of a lake are unable to harbour fish which require coolness in summer. On the other hand, chlorophyll-bearing plants, which are, of course, restricted to the photic zone, consume carbon dioxide and give in return oxygen. Thus, at springtime the upper waters of lakes have frequently been found supersaturated with oxygen owing to the luxuriance of algæ; in pond-waters the abnormal content of 24 c.c. per litre has even been reported. Here again, then, seasonal variations are all-important. Nitrogen is little influenced by animal or plant life; but, in sea-water at any rate, some bacteria are known which assimilate nitrogen, and others which set it free as gas from nitrogen compounds.

These superficial considerations will suffice to show that the biological economy of lakes is intimately bound up with the dissolved gases, and it may be hoped that the study of these gases, experimental difficulties notwithstanding, will play a greater part in limnology than it has done heretofore.

AN EPITOME OF A COMPARATIVE STUDY OF THE DOMINANT PHANEROGAMIC AND HIGHER CRYPTOGAMIC FLORA OF AQUATIC HABIT, IN SEVEN LAKE AREAS OF SCOTLAND.

(*With nine Plates.*)

By GEORGE WEST

PART I.—INTRODUCTION

This paper is mainly an epitome of work done on behalf of the Scottish Lake Survey under the direction of Sir John Murray and Mr Laurence Pullar, the full details of which have been already published by the author in the following contributions to the subject :—

(1) "A Comparative Study of the dominant Phanerogamic and Higher Cryptogamic Flora of Aquatic Habit in Three Lake Areas of Scotland" (with fifty-five plates), *Proc. Roy. Soc. Edin.*, Session 1904–5, vol. xxv. pp. 967–1023, 1905.

(2) "Notes on the Aquatic Flora of the Ness Area," *Geogr. Journ.*, vol. xxxi. pp. 67–72, Jan. 1908.

(3) "A Further Contribution to a Comparative Study of the dominant Phanerogamic and Higher Cryptogamic Flora of Aquatic Habit in Scottish Lakes" (with sixty-two plates), *Proc. Roy. Soc. Edin.*, Session 1908–9.

From the first dawn of modern science until almost the middle of the last century, the chief aim of those who interested themselves in vegetation, beyond the ornamental, useful, or medicinal properties of plants, was in the accumulation of dried specimens into herbaria, in the grouping of the plants into families so as to exhibit as nearly as possible their natural relationships, in giving names to the various species, and in appending to each a curt diagnosis of a few prominent external features in a language that could be understood only by the initiated; the great desiderata of botanists being, to have a vast number of species in their collections, and to be constantly adding still more. To a certain extent these studies were useful, but it was most unfortunate for the cause of science that such desires and methods should have dominated the fields of botany so long. With the advent, however, of such master-minds of science as Charles Darwin, Herbert Spencer, Hermann Müller, Julius Sachs, the Hookers, and many others a new era arose, and then botanists began to consider plants under the refulgent rays of the new light which these men had kindled: the real study of nature then began. Instead of the *ultima Thule* of botanists being the addition of one more plant to their lists, men began to thirst for a knowledge of the phenomena of plant life and its causation—for, in fact, a Philosophical Botany. In his *Principles of Biology*, Herbert Spencer gave the keystone to the arch when he wrote therein :—" Everywhere structures in great measure determine functions; and everywhere functions are incessantly modifying structures. In nature, the two are inseparable co-operators; and science can give no true interpretation of nature, without keeping their co-operation constantly in view."

The first plant life that occurred upon the earth was probably of aquatic habit, and water has ever continued the very soul of vegetable existence, without which its life is impossible.

When the ancestors of our present terrestrial phanerogamic flora began their phylogenetic development from aquatic forms of plant life, their first need must have been an efficient water-transporting system. As the new forms began to extend into places more remote from watery environments, so the need for rapidly carrying water through the plant-body would increase. Those forms unable to respond to this requirement would die out, and their places would be occupied by others more fitting. After enormous epochs of time, during which the struggle of adaptation has proceeded apace, it comes about that at the present day the terrestrial plants that dominate the surface of the earth are chiefly those that have best succeeded in providing themselves with an efficient water-transporting system. With phanerogams of aquatic habit there is no necessity for the elaborate development of this arrangement. When, therefore, a normal terrestrial plant is compared with one of aquatic habit, it is found that their external and internal morphology differ markedly. On the other hand, plants that inhabit very moist environments exhibit an intermediate stage.

From the foregoing remarks it must not be imagined that our aquatic flowering plants are the representatives of the ancestral stock from which the terrestrial types have arisen. It is rather the opposite, for there are good reasons for considering the existing aquatic phanerogams to have taken their origin from terrestrial types; not because they were first driven off the land by more robust competitors, as is sometimes stated, but, more probably, because certain mutable forms have exhibited a tendency, as some do even now, to take on the aquatic habit, that mode of living being more agreeable to their requirements. Many plants have both aquatic and terrestrial forms: when submerged, their structure will exhibit the points of typical aquatic types: when growing out of the water, they tend towards the morphological structure of terrestrial plants: such plants are amphibious. What then is the difference between these two opposite forms of plants?

The normal terrestrial plant takes in the greater part of its water and nutrient salts from the hygroscopic water of the soil by means of the osmotic action of delicate hairs and tissue situated near the extremity of the rootlets. This sap, beyond providing for the maintenance of turgidity, is of little use to the plant until it has been conducted into the leaves. There, with the carbon derived from the atmosphere, it is converted into various substances for the present and future requirements of the plant and its offspring. Hence the necessity to such plants for the means of rapidly transporting this ascending sap from the root-tips to the leaves. The stem being aerial, there is no necessity for the storage of a very large amount of air. In accordance with the œcological conditions that exist where they grow, terrestrial plants have to provide themselves with a more or less thickened cuticle in order to prevent the untimely evaporation of the sap.

The physical properties of water induce in aquatic plants conditions of structure quite different. Water and the nutrient salts in solution are absorbed by the whole of the submerged plant-body. Instead of being under the obligation to search for food-salts, fresh supplies are constantly being brought by the currents, which, owing to physical and mechanical causes, are of never-ceasing occurrence. Being therefore semi-independent of the root system, the latter has usually but feeble development and is often not produced at all. In order that this general absorption may take place, and the sap being in no danger of undue evaporation, no thick cuticle is developed on the submerged portion. This explains why aquatic plants wilt so rapidly when exposed to the air. The epidermal cells of aquatic plants often contain chloroplasts, which is not the case in terrestrial plants. Absorption not being restricted to the tips of distant roots, a less elaborate sap-transporting system will suffice. Owing to the support afforded by water, the lignified elements of the vascular bundles are often reduced to a minimum; the tissues are mostly parenchymatous and the walls of the cells are thin. Being shut off from an adequate supply of air, aquatic plants have to arrange for the storage of considerable quantities of this necessity; they have therefore provided themselves with very large reservoirs in the form of intercellular spaces. These air-spaces are often very large and continuous; a person may, for example, quite easily blow through the petiole of a water-lily six or seven feet long. The air in these intercellular spaces varies with the metabolic activities, and is often held under a negative pressure.

Terrestrial plants, being obliged to protect themselves against the excessive evaporation of their sap by means of a waterproof cuticle, which is also impervious to air, are under the necessity to provide a means by which an interchange of the external air with that of the intercellular spaces may be brought about; at the same time this interchange must be under the complete control of the individual. All this is accomplished by means of stomata and lenticels. The latter are quite unknown in aquatic plants as there is no secondary thickening, and the stomata only occur upon organs exposed to the air, as upon the upper surface of floating leaves. Aquatic plants often exhibit a marked variance between their submerged and floating leaves. Ranunculus peltatus, Potamogeton heterophyllus, and Apium inundatum may be cited as examples, all of which may have broad floating leaves and narrow, thread-like submerged ones. Terrestrial plants, however, may exhibit similar features in their upper and lower leaves, but for a different reason.

The flora of rapidly flowing water is limited to such species as root firmly in the substratum. Such water contains a much greater supply of air than does still water; consequently plants that thrive in this kind of habitat have relatively smaller internal air reservoirs than have those plants that inhabit still ponds and lakes; they also have a greater development of mechanical tissue. In rapidly moving water, plants have a much greater supply of food-salts presented to them in the form of matter in solution than is the case in still water of the same composition. This, in conjunction with the pull exercised upon them by the current, has a tendency to induce the production of a larger plant-body, their stems and leaves being elongated in the direction of the stream. As a result of this excessive vegetative development, such plants frequently flower less profusely than would be the case were they living in still water, owing to the antagonism existing in all organic beings between the vegetative and the reproductive systems.

From certain points of view plants may increase in interest and value in ratio to their rarity; of equal worth philosophically are those plants that occur in great abundance. The former being scattered as individuals, or as small associations over restricted areas, are possibly at present of but small import in the economy of nature. The commoner plants, however, by reason of their dominance and abundance, become important agents, not only as a plant-covering to the earth, but also in the effect they produce in the physiography of a country: barren tracts become heath or forest by the extension of vegetation; lakes are converted into morasses, moors, or even into land suitable for agriculture by the accumulation of plant-remains. Such natural operations tend to increase the wealth and social prosperity of man. As examples on the other hand, the sudden increase of a baneful fungus may bring ruin to thousands of agriculturists, and carry famine to the million; or morasses in hilly districts may slide into cultivated valleys, and completely overwhelm sites of human activity and wealth. These and many other phenomena are brought about by the predominance of certain classes of plants. How great, therefore, are the interests awakened upon the fields of practical thought and knowledge by the abundant and dominant plants in their never-ceasing antagonism with one another and with other forces of nature!

The investigations described in the pages that follow were undertaken chiefly to show which are the dominant plants, of higher organisation, in some of the lochs of Scotland, and their distribution therein; together with a few observations upon the leading factors that control the growth and extension of such plants.

During the last great glacial epoch it is certain that all forms of the higher plants were banished from the greater portion of Scotland. Towards the end of that era, as the mantle of ice and snow began to retreat, so would plants encroach again over the country from the region to the south where its influence had been less severe. What precise causes influenced most this gradual northward march of aquatic and terrestrial plants cannot now be determined, but undoubtedly they were such as affect the distribution of plants at the present day. The plants, no doubt, followed the lines of least resistance and greatest traction, not only in their geographical advance but also in their adaptations of structure and function to the varying environments. These lines must necessarily be ramified and involved, perhaps to an insoluble degree, yet on them are the secrets of plant-geography to be discovered, on the basis of physiological anatomy and plant-psychology. By such methods a most interesting inquiry would be—What is the equilibrium that has been attained between the forces of resistance and traction that has caused certain species to arrive at, and remain in, restricted areas?

The two great factors that contribute towards the distribution of the plant-covering over the surface of the earth, and through its waters, are food and climate. Notwithstanding the conditions for plant life being so often remote from the ideal, yet the plastic power that plants possess of adapting themselves to the various combinations of edaphic and climatic conditions is so great that there are comparatively few spots in which some plant or other is not able to thrive and carry on its metabolic activities. With aquatic plants the influence of the substances, food or otherwise, held in solution in the water, is vastly greater than that of climate.

The edaphic conditions dominating the flora in the majority of highland peaty lochs are indirectly influences of climate. Indeed, the rock-basins that contain the lakes are themselves chiefly the result of climatic effects, because they were scooped out during a former period of glaciation. This is also to a great extent true of the lowland lochs, such, for example, as those of Fife. The study of the lake flora leads, therefore, to the consideration of the cause of a glacial epoch, and is thus the usher to a most abstruse problem.

The yellow-brown colour of the waters of the Highland districts is a matter of common observation, and is due to the water-supply from the mountains percolating through enormous quantities of peat before reaching the lakes. This, then, would appear to be an edaphic influence, and so it is, but the existing conditions—the presence of peat on the mountains—have been brought about by direct climatic influence. The climatic conditions that obtain in the exposed portions of the Highlands are more favourable to the natural productions of moorland than of either forest or grass-land. These three formations of dominant types of vegetation—moor, forest, and grass—are antagonistic to one another, the tendency being for the moorland vegetation to extend from the higher situations over the natural forest and grass-land of the lower altitudes, to their extinction. The principal natural causes for the victory of moor over forest and grass are:—(1) wind, which is much less antagonistic to moor plants than to trees, because the former are much nearer the earth, and therefore feel the destructive desiccating action of wind very much less than trees do; besides which the dominant moor plants have protective adaptations against wind which trees seldom possess; (2) the peculiar acid humus that is formed so abundantly, in the form of peat, from the remains of certain dominant moor plants, and which acts inimically towards trees and most lowland grasses. These natural conditions have undoubtedly been unwittingly hastened during the past two thousand years by the destructive influence of man on forest. Then, in this country, forest is antagonistic to the grass-land of the lowlands because of climatic influences.[1]

It is the presence of the peat extract in the water that is the dominating factor governing the flora in peaty lochs. Its presence excludes directly a number of aquatic or semi-aquatic plants that might otherwise thrive there. It obliterates any small quantity of calcium carbonate that might be present, and thus renders the water untenable to calciphilous plants. On the other hand, certain calcifugal plants, having become accustomed to tolerate the presence of humic acids, abound. I scarcely know that one should say the latter thrive the better through lack of competition with the former, for commonly it is not because competition for available space is so great, but because the local conditions favour the dominant production of a few individual species.

By reason of the preserving action of humic acids, the organic remains in shallow water about the shores of the lakes do not readily decay, but undergo a slow process of disintegration, and form a sort of liquid peat. Owing to this action, suitably situated shallow places about peaty lakes become reclaimed by the growth of land-winning plants quicker than is the case in lakes that are free of humic acids. A similar preserving action prevents the rapid decay of organic remains at the bottom of the lakes, and in cases where the latter are comparatively shallow, and where a large amount of foreign vegetable detritus is carried in by streams, etc., this substance accumulates at the bottom and prevents the development of plants that would otherwise thrive there. This is a common feature in the lochs of Area IV.

The peat extract darkens the water, and this restricts the depth zone to which submersed aquatics will grow, because they are unable to carry on photosynthesis beyond a very limited depth, owing to want of light. In peaty water, therefore, the photic zone, throughout which there exists sufficient light for the proper development of the higher plants, does not extend to a greater depth than about 30 feet, and is frequently very much less than that.

The extreme depth to which such plants as Nitella opaca and Fontinalis antipyretica will flourish in peaty water may roughly be estimated by multiplying by four the greatest depth at which one can see the gravel at the bottom, when looking over the shaded side of a boat about midday in the summer, when the sun is shining brilliantly, the water being perfectly calm, and the boat still. Such a

[1] The involved complications brought about by these factors cannot be explained here, for want of space.

depth in Loch Ness and others is from 7 to 8 feet; in many peaty lochs, however, this depth is considerably less. This multiplier, however, does not hold where the multiplicand is considerably greater. Thus at Loch Fiart, on the island of Lismore, the bottom may be seen at a depth of 25 feet under the above conditions, but plants do not thrive there at a greater depth than 45 feet. Possibly this is because the less refrangible rays of the spectrum, which are most necessary for photosynthesis, become insufficient at greater depths, although the rays of shorter wave-length may penetrate to greater depths in sufficient quantity to fulfil the requirements of the metabolic activities that are dependent upon them. It must be borne in mind that the yellow-brown colour of the water of peaty lakes probably neutralises the photo-chemical action of the violet rays at no great depth. It is known that Rhodophyceæ thrive in the sea to at least a depth of 250 feet, but in all probability their reddish colour accentuates the photo-chemical action of the very feeble yellow-green rays [1] that penetrate such a depth of water. In similar manner a photographic plate becomes more sensitive to certain rays when its film is stained with suitable colours. Thus a film stained with erythrosin becomes sensitive to green and yellow. Exact information on these points in various waters of Scotland is much needed.

In the littoral region of the sea are found well-marked zones of vegetation, in which the plants of one trespass but little upon the domain of the others. This is to a great extent dependent upon the rise and fall of the tide. In fresh water, however, such well-differentiated zones cannot be distinguished. Still it appears that certain plants usually grow in certain relative positions, where some species form distinct colonies; but many others frequently, and in fact generally, encroach very much upon one another (*vide* Table, p. 193). It is, perhaps, convenient to imagine a set of zones for both the semi-aquatic and the submerged flora of a loch, but the plants are in no way enslaved to any set rule, excepting that many are restrained by certain œcological and physical conditions as mentioned hereafter (p. 164). As an example of a species that readily adapts itself to varying conditions, mention may be made of Fontinalis antipyretica. This plant grows in water of all depths down to 40 feet, as at Lismore; it also grows equally well in the rocky bed of a burn that has water in it only during floods, as near Inchnacardoch Bay, Loch Ness; again, it is frequently found in swiftly running streams, as well as near waterfalls.

As has been already indicated, a most important factor in the dis-

[1] The rays for maximum photosynthesis in the red seaweeds are the yellow-green; these penetrate water sufficiently for photosynthesis to about five times the depth that red rays do.

tribution of submerged plants over the bottom of a lake is the amount of suitable light available. It is, therefore, usual to distinguish three different zones according to the intensity of the received light. These zones vary in magnitude in different localities, in accordance with the amount of suspended matter in the water, together with the declivity of the sides of the lake-basin. The following are recognisable:—

(1) A photic zone, throughout which there exists sufficient light for the proper development of the higher flora. This zone may extend to a depth of 40 feet as at Lismore, to only 12 feet as at Loch Kemp, or in many lochs even much less. Deeper than this zone there is—

(2) A dysphotic zone, in which a few of the higher plants, stragglers from the photic zone, may struggle to exist. This zone is normally occupied by members of the lower cryptogamic flora that are able to thrive with a minimum of light. Deeper still there is—

(3) An aphotic zone, in which no light-demanding organism can exist.

The last glacial epoch, after destroying the vegetation of Scotland, immediately began the formation of more numerous lake-basins for the reception of a greater aquatic flora after its disappearance. Not only this, but other results of glaciation are found actually dominating the vegetation in certain of the lochs at the present moment. At Lochs Oich and Lochy, for example, the sides of the adjacent mountains are coated with glacial drift-gravel. This gravel is brought into the lochs by the numerous burns in great abundance, and deposited upon the shores. Under the erosive power of the waves, the constant movement of this gravel upon the littoral entirely prevents the growth of aquatic phanerogams over a considerable area of the margin of the lochs. Again, in many places a steep escarpment, due to glacial action, enters a lake immediately, so that water too deep for phanerogams occurs without any shore whatever; instance Loch Ness opposite Invermoriston, where a depth of 652 feet may be sounded at 120 yards from the margin. Here we see the indirect effect of a past epoch upon the flora of existing lakes, the lakes themselves being the direct result of that period.

Climate also affects the local distribution of the plants in each loch more or less. The prevailing and frequently strong winds are westerly; consequently there is upon the eastern shore of a lake a very considerable and oft-recurring wave-action. Acting upon a rocky or stony shore, this erosive power entirely prevents the growth of the higher plants in the shallow water where its influence is felt. Unless sheltered by adjacent hills, all the lakes will therefore be almost or quite devoid of vegetation on their eastern shores, whilst the western shores, and bays sheltered from the prevailing wind, may have an abundant vegetation. The Algæ of the seashore may be cited as an example, on the other hand, that plants can develop, and luxuriantly too, on a rocky shore subjected to powerful erosion; but the case is here entirely different. The seeds of phanerogams, excepting the tropical Podostemaceæ, have no power to firmly attach themselves to rocks and stones, as have the spores of seaweeds. Still we do find, even in exposed parts of the lakes, fixed rocks often covered with mosses, hepatics, Algæ, etc. Wind is also an important factor in dwarfing the semi-aquatic vegetation about the littoral region of the lakes; especially is this the case with those that are situated in the more elevated and exposed positions.

The sudden rise or fall of water to any great or prolonged extent is inimical to the well-being of plants in the lochs, particularly so if the water is extremely peaty. This is very pronounced at Loch Mhor, where an ever-changing level—due to the rainfall on the one hand, and the water used by the British Aluminium Company at Foyers on the other hand—does not allow a flora to grow at all.

The great variation between the summer and winter temperatures of the water of the higher mountain lochs doubtless affects the flora to a greater extent than in those of lower altitude. These hill lochs are often shallow, and the comparatively small body of water may become heated to 70° Fahr. in summer, and may frequently be covered with ice in winter and spring, the ice often remaining upon such lochs until April. Before its final disappearance, large shoals of broken ice grind upon the shores with surprising power and noise, and would destroy any littoral vegetation within its influence. Considering that such floating ice shifts about the loch with every change of wind, it is scant wonder these hill lochs are so often found devoid of marginal vegetation. In the great body of water of the large and deep lochs of lower altitude, the temperature is more equable, winter and summer records not varying more than 10° to 20° Fahr., and such lochs seldom freeze.

In the peaty lochs the aquatic plants are usually remarkably free of epiphytic organisms and also of mud. Humic acids, and perhaps carbonic acid too, in the waters almost extinguish molluscan life. Consequently, one does not find the aquatic vegetation destroyed by these creatures as is commonly the case where certain of them, especially Limnææ, abound. There being little or no calcium bicarbonate in peaty waters, there is consequently no incrustation of calcium carbonate upon the aquatic plants. A necessary corollary to such antecedents is that no lime deposit resulting from the metabolism of plants is being laid down in these peaty lochs, as is the case where the water is charged with calcium bicarbonate. In the lochs at Lismore, for instance, the mud at the bottom is gray in colour, and feels gritty to the touch, which is due to the lime from the plants.

The mud occurring in peaty lochs is seldom of the black, evil-smelling kind, such as is commonly found in non-peaty lochs. This will be explained subsequently (p. 215).

Many plants, *e.g.* Phragmites communis, Sparganium ramosum, Alisma Plantago, etc., always grow more luxuriantly when the mud is black and fetid; but other plants, *e.g.* various species of Sphagnum, Isoetes lacustris, Lobelia Dortmanna, etc., are unable to endure that kind of mud, not directly because of its presence, but because other factors, *e.g.* difference in food-salts, are correlated with the presence of this or that kind of mud. A number of other plants are comparatively indifferent, *e.g.* Castalia speciosa, Menyanthes trifoliata, Carex rostrata, etc. It would be interesting to grow aquatic plants artificially in œcological conditions opposed to their usual natural habitat, and to study the results.

From the foregoing and subsequent statements it will be readily understood that the flora of the lochs is subjected to many varying conditions. Now, in order to maintain a proper tone of health a plant has of necessity to respond in suitable ways to all the varying external impressions. A plant is therefore in a constant and continual state of change, owing to the never-ceasing mechanical, physical, and chemical changes of its unstable environment. The plastic nature of many plants enables them to modify their organs in reciprocation to any fairly constant set of environmental conditions; and it is in this endeavour to accommodate themselves for the maintenance of healthy existence in inhospitable places, that certain deviations from the normal forms of more kindly environments are to be accounted for. That such forms should receive definite specific, or in some cases even varietal, names is open to grave doubt. Physiologists and experimental botanists are becoming more and more sympathetic towards the simplicity of the astute George Bentham; and whilst recognising, as did Bentham, the numerous forms fixed and transient, such are regarded as unit forms in the phylogenesis, or in the retrogression of a species. Owing to the variability of individuals, a species is sometimes held to consist of an aggregate of various forms or units which deviate more or less from a type form, *i.e.* from the species proper. Such unit forms some botanists elevate to the rank of varieties and even species. In the *British Flora* by George Bentham, 5th ed., 1887, there are, for example, seven species of Hieracium; whilst in the *Manual of British Botany* by Charles Babington, 9th ed., 1904, by H. and J. Groves, almost the same material is made to yield ninety-seven species, besides numerous named varieties. To such extreme tenuity have the diagnoses of these variable plants been drawn that the most learned authorities are often unable to distinguish the different species by one another's descriptions. Besides the above-mentioned, another reason for variation is presented in the case of aquatic plants that have within comparatively recent times undergone the transformation from terrestrial to aquatic habit. We may well suppose the character of such to be very variable and unstable—to be, in fact, veritable puzzles to the botanical collector. When we find in a plant such instability of character for no apparent reason, we may *a posteriori* assume the probability that a somewhat recent evolution has taken place from terrestrial progenitors.

In many districts mountain lochs may be distinguished by the presence of certain plants, as, for example, Isoetes lacustris, Lobelia Dortmanna, Juncus fluitans, Callitriche hamulata, Sparganium minimum, etc., and by the absence of reeds at the margin. But in the Loch Ness Area such is not always the case, the presence or absence of any such plants being no criterion of the elevation of a loch. All the plants enumerated are to be found at so low a level as Loch Ness (52 feet above sea); and a reedy margin sometimes occurs in quite highland situations, whilst it is almost absent in such low-lying lochs as Oich and Ness. The reason for the presence or absence of certain plants is not altogether one of elevation, but is rather due to the supply of food-salts, and the amount of exposure of the water to winds, coupled with the nature of the shore. The mountain lochs usually drain a very small area, poor in food-salts and rich in acid humus; consequently, only those plants are found in them that can obtain their requirements from an apparently scanty food-supply, combined with the presence of humic acids. Such plants are those that have been associated with mountain lochs. Lowland lakes usually drain a wider area, and soils poor in peat and rich in food-salts, which, although indispensable to most plants, are poison to others. In the area of Lochs Ness and Oich there is but a small amount of soil rich in food-salts available for drainage, compared with the soil poor in food-salts and rich in acid humus. Consequently, the effect of drainage from a small, rich food-area is almost extinguished by the humic acids, and in such lowland lochs the vegetation is identical in species with that of the highest mountain lochs. Again, in Lochs Oich and Ness (and, of course, others) there is practically no reedy margin, neither does such a formation occur in many mountain lochs. The reason for this is the nature of the shore, combined with the erosive power of the waves, leaving food-supply altogether out of the question. On the other hand, in mountain lochs with a sheltered peaty or muddy shore, as in lowland lakes of like nature, there is a reedy or sedgy margin. Highland lochs are usually in situations fully exposed to the fierce winds, and their shores are rocky or stony; consequently, they have few plants about their margins. Their water, being generally poor in food-salts and rich in humic acids, has a restricted flora; but the same conditions may obtain in the lowlands, when the flora of the lochs will be similar to the flora of those on the mountains. On the other hand, a highland loch having a supply of food-salts, with a suitable shore and sheltered from prevailing winds, may quite well have the character of a lowland loch regarding its flora (see Plates).

In the list of the plants hereafter, the numerals following the name of each plant after the authority, refer to the areas at the lochs in which the plant occurs, as follows:—

Area I. The Ness district.
,, II. The Island of Lismore.
,, III. The Nairn district.
,, IV. N.W. Kirkcudbrightshire.
,, V. S.E. Kirkcudbrightshire.
,, VI. Wigtownshire.
,, VII. Fife and Kinross.

My friend Mr James M'Andrew, who resided many years in Kirkcudbrightshire, and whose discoveries in the geographical distribution of plants have so greatly enriched the written records of the flora of this and the adjoining counties, especially amongst the Cryptogams, has rendered me many services. Naturally, he has had opportunities of observation there that have been denied to me; the records that he has kindly furnished, where my own were deficient, are acknowledged by being placed in brackets with his initials.

PART II.—LIST OF THE PLANTS

RANUNCULACEÆ

Ranunculus aquatilis, *L.*, I., II., III., IV., V., VI., VII. It was frequently impossible to determine the exact form of the Batrachian Ranunculi that were observed, owing to the absence of flowers, fruit, or other data by which the numerous forms are distinguished as species. When such was the case I have simply enumerated the specimen in hand as Ranunculus aquatilis.

Ranunculus Drouetii, *F. Schultz*, V., VI., VII. Not general, although occasionally found, in lowland lochs.

Ranunculus Baudotii, *Godr.*, VII. Preceding remarks apply to this species also, but it is more abundant.

Ranunculus circinatus, *Sibth.* II., very scarce. VI., VII., occasionally abundant in lowland lochs; at Kilconquhar Loch, for example, it covers a large area of the water and presents a magnificent spectacle when in flower.

Ranunculus peltatus, *Schrank*, IV., V., VI., VII. Widely distributed and sometimes very abundant.

Ranunculus heterophyllus, *Weber*, IV., V. Occasionally very abundant; in Loch Ken, for instance, it overgrows considerable tracts of shallow water at the margin of the loch, and when in flower is extremely picturesque.

Ranunculus Lenormandi, *F. Schultz*, V. On mud at the margin of lakes, but scarce.

Ranunculus hederaceus, *L.* I., very scarce. VII., frequent on the muddy shores of lochs. In Areas IV., V., and VI. it is frequent about streams, etc., but is seldom seen at the lochs.

Ranunculus sceleratus, *L.*, VII. On muddy shores, but very scarce.

Ranunculus Lingua, *L.*, V., VII. On marshy ground about lowland lochs; restricted in distribution, but abundant where it does occur.

Ranunculus Flammula, *L.*, I., II., III., IV., V., VI., VII. Normal forms are abundant nearly everywhere below 1000 feet above sea-level.

Ranunculus scoticus, *Marsh.*, I., IV. Abundant on the shores of mountain lochs.

Ranunculus Flammula, *L.* A prostrate form rooting profusely at the nodes, similar to var. pseudo-reptans but much larger, is sometimes found upon the stony shores of lochs in all the Areas, but is especially abundant at Loch Ken.

Ranunculus Flammula, *L.*, var. pseudo-reptans, *Syme*, VII. Scarcely distinguishable from the true R. reptans. It has, however, a broader achene which is more suddenly contracted into a beak than R. reptans, and the stem structure differs in having 3 vascular bundles, instead of 5–7 as in R. reptans.

Ranunculus reptans, *L.*, VII. On flat, exposed sandy places, that are either bare or covered with short turf, all around Loch Leven.

Ranunculus Flammula, *L.*, var. natans, *Pers.*, IV. Submersed, with a stem 12 to 30 inches long, having a few radical leaves 3 to 8 inches long, with a small spathulate or elliptical lamina ½ to 1 inch long. A number of roots and a fascicle of leaves, similar to the radical leaves, but smaller, are given off from every node. It is very abundant in the neighbourhood of Lochs Recar, Ballochling, etc.

Caltha palustris, *L.*, I., II., III., IV., V., VI., VII. An abundant plant about lowland lochs, especially in Area VII.

Caltha palustris, *L.*, var. minor, *Syme*, I., IV. On the shores of mountain lochs. No doubt this is a depauperated form of C. palustris.

NYMPHÆACEÆ

Castalia speciosa, *Salisb.*, I., II., IV., V., VI., VII. Very common and abundant, especially where the water is not very peaty.

Castalia speciosa, *Salisb.*, var. minor, *DC.*, I., IV. In mountain lochs. Probably a depauperated form of C. speciosa.

Nymphæa lutea, *L.*, II., IV., V., VI., VII. Common and abundant, often overgrowing large areas, but seldom seen in the hill lochs.

Nymphæa lutea, *L.*, var. intermedia, *Ledeb.*, V., VII. Grows with the larger form and sometimes alone, chiefly in the lower portion of Loch Ken, where it is very abundant. Rare in Area VII.

Nymphæa pumila, *Hoffm.*, I., IV. Not common; chiefly at Lochs Meiklie, Ken, and Stroan.

CRUCIFERÆ

Radicula officinalis, *Groves*, II., III., V., VI., VII. Seldom abundant at the lakes.

Radicula palustris, *Mœnch*, V., VI., VII. Occurring sporadically about the shores of lowland lakes.

Radicula pinnata, *Mœnch*, V. Distribution very restricted.

Cardamine pratensis, *L.*, I., II., III., IV., V., VI., VII. Almost ubiquitous, but frequently sparse. A form which multiplies vegetatively by buds, that arise from the base of the leaflets, occurs at Loch Gelly.

Subularia aquatica, *L.*, I., a few plants occasionally observed. IV., V., VI., often very abundant.

VIOLACEÆ

Viola palustris, *L.* I., II., III, only as scattered specimens upon the shores of lakes. IV., V., VI., VII., frequently abundant in lowland situations.

ELATINACEÆ

Elatine hexandra, *DC.*, VI. Very abundant in places. Two forms occur:—When submersed the plants are of a delicate texture, pale green, with elongated leaves, and seldom flowering. When exposed on mud or sand they are much more robust, dark reddish green, with short leaves, and flower profusely. In this condition the plants much resemble small specimens of Peplis Portula in both form and colour.

CARYOPHYLLACEÆ

Sagina nodosa, *Fenzl*, VII. In matted growth on sandy or stony shores; scarce.

Stellaria uliginosa, *Murr.*, I., II., III., IV., V., VI., VII. Widely distributed, but seldom very abundant.

Stellaria palustris, *Retz.*, V. Scarce.

Silene maritima, *With.*, I. About the shores of Loch Ness.

HYPERICACEÆ

Hypericum humifusum, *L.*, V. Wet sandy and gravelly shores; not common, and usually a straggler from an adjoining heath.

Hypericum elodes, *L.*, IV., [V., J. M'A.], VI. Sometimes very abundant, but always in peaty water.

ROSACEÆ

Spiræa Ulmaria, *L.*, I., II., III., IV., V., VI., VII. Widely distributed and frequently very abundant, but chiefly about lowland lakes.

Comarum palustre, *L.*, I., II., III., IV., V., VI., VII. Remarks on the preceding species apply to this also.

LYTHRACEÆ

Peplis Portula, *L.*, I., IV., V., VI., VII. Aquatic and terrestrial forms are common about the shores of lochs, but chiefly lowland. A very robust terrestrial form was found at Loch Barhapple; whilst at Loch Doon a submersed form grew to a depth of 3 feet in abundance.

Lythrum Salicaria, *L.*, II., IV., V., VI., VII. Frequently very abundant on the shores of lochs, chiefly lowland, but rare in Area VII.

ONAGRACEÆ

Epilobium angustifolium, *L.*, I., VI. Very scarce at the lochs.

Epilobium palustre, *L.*, II., VI., VII. Usually with other herbage in marshy places on the shores of lochs.

Epilobium tetragonum, *L.*, IV., VII. Scattered sporadically in a similar way to the preceding, but this is a less frequent species, and is usually scarce.

Epilobium hirsutum, *L.*, I., VII. Seldom abundant, but occasionally dominant over a small area of marshy shore. Of common occurrence in ditches and by rivers.

HALORAGACEÆ

Hippuris vulgaris, *L.*, I., II., III., [V., VI., J. M'A.], VII. Occasionally very abundant.

Myriophyllum alterniflorum, *DC.*, I., III., IV., V., VI., VII.

Generally very abundant, but it usually seems to require water that is more or less peaty. In lowland non-peaty lochs that receive the drainage of villages M. spicatum takes its place. It is very exceptional to find the two species in the same water.

Myriophyllum spicatum, *L.*, II., V., VI., VII. Abundant where the water is not peaty; see remarks on the preceding species.

CALLITRICHACEÆ

Callitriche vernalis, *Koch*, VI., VII. Not common, but sometimes occurs in sheltered bays or in shore pools.

Callitriche stagnalis, *Scop.*, I., III., IV., V., VI.,VII. Terrestrial and aquatic forms are rather common in shallow places and pools about the shores of non-peaty lochs.

Callitriche hamulata, *Kütz.*, I., III., IV., V., VI., VII. Widely distributed in peaty water, and particularly abundant in Area I., where it occurs in almost every loch, and is frequently a dominant species. It is usually found without the floating rosettes; but in a few places—Loch Stroan, for example—the two forms occur.

Callitriche autumnalis, *L.*, V., VI., VII. This fine species is widely distributed in non-peaty lowland lochs, and it is frequently very abundant and even dominant.

PORTULACEÆ

Montia fontana, *L.* Aquatic form, syn. *M. rivularis*, *Gemel.*, I., II., V., VI., VII. A very common plant about the shores of some of the less peaty lochs, both in aquatic and terrestrial forms.

SAXIFRAGACEÆ

Parnassia palustris, *L.*, I., II., IV., [V., VI., J. M'A.], VII. Occasionally represented on boggy shores.

UMBELLIFERÆ

Hydrocotyle vulgaris, *L.*, I., II., III., IV., V., VI., VII. The ordinary form abounds nearly everywhere on the shores of lochs. At Barlockhart Loch there occurred a floating form having stems from 30 to 50 inches long, and leaves only about half an inch in diameter.

Apium nodiflorum, *Reichb.*, V., VII. Scarce, seldom seen as a constituent of a loch flora.

Apium inundatum, *Reichb.*, I., IV., V., VI., VII. Sometimes very abundant, but always in water that is not very peaty. It usually occurs from the margin to 3 feet, and occasionally even to 6 feet deep, reaching the surface from that depth.

Carum verticillatum, *Koch*, IV., V., VI. This is one of the characteristic plants of the lowland parts of Galloway; in wet meadows, moors, and about the shores of lochs.

Cicuta virosa, *L.*, V., VII. As a member of a loch flora I have only observed this plant at Carlingwark Loch, where it is abundant, and at Otterston Loch.

Sium angustifolium, *L.*, [VI., J. M'A.], VII. Always scarce.

Œnanthe crocata, *L.*, I., IV., V., VI. In the lowland parts this is a common plant on the marshy shores of lochs.

Angelica sylvestris, *L.*, VII. Occasionally on marshy shores.

RUBIACEÆ

Galium palustre, *L.*, I., IV., V., VI., VII. Frequent on the marshy shores of lochs, although scarce in Area I.

VALERIANACEÆ

Valeriana officinalis, *L.*, IV., V., VI., VII. Sometimes abundant at the marshy shores of lowland lochs. It occurs in Area I., but upon one occasion only were a few specimens observed at a loch.

COMPOSITÆ

Eupatorium cannabinum, *L.*, II., VI. Only observed at Lismore and about the lochs of the Mochrum district (see p. 241). [Often found in damp places by the seashore of Wigtown and Kirkcudbright.—J. M'A.]

Gnaphalium uliginosum, *L.*, VI., VII. Sometimes it forms a loose sward on damp shores.

Bidens cernua, *L.*, V., VI. Distribution restricted, and plants usually scarce.

Senecio aquaticus, *Hill*, I., II., IV., V., VI., VII. Frequent about the shores of lowland lakes.

Serratula tinctoria, *L.*, IV. This southern plant is well established in dry bushy places about the shores of Loch Ken.

Cnicus palustris, *Willd.*, VII. In this Area it is frequently very abundant about marshy shores. In other Areas, although a common plant, I have not seen it in any abundance on the shores of the lakes.

CAMPANULACEÆ

Lobelia Dortmanna, *L.*, I., III., IV., V., VI., VII. Frequently very abundant, but only in lochs that are more or less peaty.

GENTIANACEÆ

Menyanthes trifoliata, *L.*, I., II., III., IV., V., VI., VII. This species is ubiquitous and thrives under all kinds of environmental conditions.

BORAGINACEÆ

Myosotis palustris, *With.*; including *M. scorpioides*, *M. repens*, *M. strigulosa*, and *M. cæspitosa.* I., II., III., IV., V., VI., VII. The characters distinguishing these are so interwoven that it is frequently impossible, in the field, to decide upon the variety in hand. Although common, they are of but small importance as a constituent of a loch flora; I have therefore included the whole in the aggregate palustris. They occur chiefly about lowland non-peaty lakes.

Symphytum officinale, *L.* Seldom found upon the shores of lochs, but it does rarely so occur in Area VII.

SCROPHULARIACEÆ

Scrophularia aquatica, *L.*, I., IV., V., [VI., J.M'A.]. Always scarce.

Scrophularia nodosa, *L.*, IV. Abundant about the shores of Loch Ken and a few other places. A few plants occur sporadically about the lochs of Area I.

Mimulus Langsdorffii, *Donn*, V., VII. Well established on the muddy, marshy shores of several lakes.

Pedicularis palustris, *L.*, I., II., III., IV., V., VI., VII. Common and widely distributed.

Veronica scutellata, *L.*, V., VI., VII. Seldom abundant.

Veronica Anagallis, *L.*, II., V. Scarce.

Veronica Beccabunga, *L.*, I., V., VI., VII. Rare in I., but in the other Areas it is often abundant about the shallow margins of lowland lakes, and frequently overgrows the shore.

LABIATÆ

Mentha aquatica, *L.*, IV., V., VI., VII. Often abundant on the marshy shores of lowland lochs. It also occurs in Areas I. and III., but very sparsely.

Mentha sativa, *L.*, I., II., III., IV., V., VI., VII. Abundant in lowland districts about marshy shores. The var. rubra, *Huds.*, occurs, but less frequently, although in Area I. it is much more plentiful at the lochs than the type.

Mentha arvensis, *L.*, I., III., VI., VII. The type or one of the varieties sometimes occurs on the dry, gravelly shores of the lowland lochs.

Scutellaria galericulata, *L.*, I., V., VII. Sometimes abundant, but usually scarce.

Stachys palustris, *L.*, IV., V., VII. Sporadically upon the shores of lowland lakes.

Lycopus europæus, *L.*, V., VI., VII. Preceding remarks apply to this species also.

LENTIBULARIACEÆ

Utricularia vulgaris, *L.*, I., II., III., IV., V., VI., VII. Generally distributed, but less abundant in the southern than in the northern Areas.

Utricularia intermedia, *Hayne*, I., IV., VI. Common in the hill lochs of Area I., but much less abundant in the southern Areas. I have seen it in pools in Area VII., but not in the lochs. I have never seen any Utricularia flowering in a loch; they appear to be continually reproduced by hybernacula.

PRIMULACEÆ

Lysimachia nemorum, *L.*, I., IV., V., VI., VII. Occasionally on the shores of lowland lochs, never abundant.

Lysimachia Nummularia, *L.*, I., IV., V., VI., VII. Remarks similar to the last.

Lysimachia vulgaris, *L.*, I., V., VI., VII. Only observed at one loch in Area I., and restricted to a very few lochs in the other Areas.

Anagallis tenella, *Murr.*, V. On the shores of a very few lowland lochs, but seldom abundant.

Samolus Valerandi, *L.*, II. Only observed at Loch Kilcheran.

PLANTAGINACEÆ

Littorella lacustris, *L.*, I., II., III., IV., V., VI., VII. Abundant everywhere.

Plantago lanceolata, *L.* Often conspicuous by its abundance on the stony shores of lochs in agricultural districts, especially in Area V.

POLYGONACEÆ

Rumex Hydrolapathum, *Huds.*, V. Scarce. The water-docks are of rare occurrence at the lakes under consideration.

Polygonum amphibium, *L.*, I., II., IV., V., VI., VII. Aquatic and terrestrial forms are abundant, but chiefly in lowland places.

Polygonum Hydropiper, *L.*, I., IV., V., VI., VII. Rarely seen at the lochs in Area I., but in the southern Areas it is frequent, although seldom in great abundance.

Polygonum Persicaria, *L.*, VI., VII. Sometimes abundant on the shores of lowland lochs.

Polygonum aviculare, *L.*, VI., VII. Sometimes overgrows the drier parts of the shores of lowland lochs.

CERATOPHYLLACEÆ

Ceratophyllum demersum, *L.*, VII. Otterston Loch is the only record for the lakes under consideration, and it grows there in extraordinary abundance.

AMENTIFERÆ

Alnus glutinosa, *Gært.*, I., II., III., IV., V., VI., VII. Frequent.

Betula glutinosa, *Fries*, I., II., III., IV., V., VI., VII. Frequent.

Myrica Gale, *L.*, I., IV., V., VI. Frequent.

Salix aurita, *L.*, I., II., III., IV., V., VI., VII. Frequent.

The above four species are the most dominant trees or shrubs that occur naturally in wet places about the shores of lakes. Many other species and genera occur, especially about the lowland lakes, but mostly on drier ground. These and the damp-loving species of Salix, Populus, etc., that are found, generally bear evidence of having been planted for shelter, ornament, or other purposes.

HYDROCHARIDACEÆ

Anacharis Alsinastrum, *Bab.*, VII. Particularly abundant in Loch Leven, but less so than formerly on account of the raids made against it by the angling authorities. [VI., Monreith Loch, —J. M'A.]

IRIDACEÆ.

Iris Pseud-acorus, *L.*, I., II., III., V., VI., VII. Frequent; often overgrowing a considerable patch of littoral marsh, but rare about the hill lochs.

ALISMACEÆ

Alisma Plantago, *L.*, I., II., V., VI., VII. Rare in I. and II., but often abundant about the lowland lochs of the other Areas. A curious submerged form occurs at Loch Gelly, and a weak, narrow-leaved form was found at Loch Fiart.

Alisma ranunculoides, *L.*, III., IV., V., VI., VII. Widely distributed, but seldom abundant. Dwarf forms about 1½ inches high occur in the exposed sandy shores of Loch Leven and other places. An entirely submersed form about 3 inches high with quite subulate leaves is occasionally found and is quite abundant at

Loch Corsock. There it flowers under water to a depth of 3 feet; without the flower-stalk these submersed forms look extremely like Isoetes lacustris.

JUNCAGINACEÆ

Triglochin palustre, *L.*, I., II., IV., VI. Scarce, and sporadically scattered about the shores of lochs.

MELANTHACEÆ

Tofieldia palustris, *Huds.*, I. About shores in peaty places; not common.

Narthecium ossifragum, *Huds.*, I., IV., V., VI. On peaty shores, but seldom abundant.

JUNCACEÆ

Juncus effusus, *L.*, I., II., III., IV., V., VI., VII. Abundant everywhere, often covering large areas of ground.

Juncus conglomeratus, *L.*, I., III., IV., V., VI., VII. On drier ground than J. effusus, and much less abundant.

Juncus glaucus, *Ehrh.*, VII. Not uncommon in some of the other Areas, but I have only observed it on the shores of the lochs in Area VII.

Juncus bufonius, *L.*, I., IV., VI., VII. Frequent about the shores of many lowland lochs, but less common at the hills. Its var. fasciculatus, *Bert.*, is sometimes found growing in dense prostrate tufts on exposed sandy shores.

Juncus lamprocarpus, *Ehrh.* (=*J. articulatus*, *L.*), I., II., III., IV., V., VI., VII. Abundant on the shores of lochs, especially where the water is more or less peaty.

Juncus acutiflorus, *Ehrh.* (=*J. sylvaticus*, *Reichard.*), I., II., III., IV., V., VI., VII. Abundant on the shores of lochs, but it is perhaps more plentiful about non-peaty lowland lochs than J. lamprocarpus.

When it could not be readily determined which of the two last species a specimen was referable to, I have called the plant J. articulatus. They both vary greatly, but I think most of the reduced forms so frequently met with are from the acutiflorus group.

Juncus supinus, *Mœnch*, I., IV., V., VI., VII. A more protean species than the last-mentioned. The normal type is of terrestrial habit and is found on the shores of lakes. Opposed to this is a submerged aquatic plant, with tresses of numerous hair-like leaves and without flowers; one might therefore easily be puzzled as to their identification. By careful searching, however, a whole chain of intermediate forms may be found. The clue to the submerged hair-like leaved forms (*Juncus fluitans*, *Lam.*) is found in shallow places with but a few inches of water. Here are found forms bearing degraded and abortive flowers, with the leaves of the submerged plant. In drier places are found intermediate forms again, often with degraded flowers, and frequently viviparous at the nodes and inflorescences. The terrestrial forms may resemble J. bufonius or certain varieties of J. acutiflorus. These terrestrial forms are usually erect, about 6 inches high, having leaves with very obscure septa and slightly channelled, flowering, and not often viviparous; such represent J. supinus, *Mœnch.* Another form, more cæspitose and dwarfed, with finer leaves, in wetter situations, flowering, not often viviparous, may be regarded as var. uliginosus. Then there is a prostrate form resembling supinus in size, but with finer leaves, inflorescences more abundant, and in whorls, often viviparous; this may be taken as var. subverticillatus. Then there are the half-submerged forms with abortive flowers and hair-like leaves from which may be recognised the submerged form with tresses of hair-like leaves, and non-flowering—var. fluitans. The last form is extremely abundant in nearly all the waters of Area I., from the highest mountain loch to Loch Ness, but there the other varieties as well as the type are all scarce. In Areas IV. to VII. the terrestrial forms are more abundant than in the Ness Area, whilst the aquatic form, var. fluitans (*Juncus fluitans*, *Lam.*), is less dominant than in the Ness Area; it is, however, fairly abundant in most of the peaty lochs of IV. and VI., but in V. and VII. it is scarce. These forms are of extreme interest; in them, apparently, may be traced the phylogenesis of an extremely abundant and dominant aquatic plant, from plastic terrestrial and sub-aquatic forms which are not now dominant in these Areas.

TYPHACEÆ

Typha latifolia, *L.*, III., V., VI., VII. Chiefly on the shores of lowland lochs, but not common, nor is it often abundant.

Typha angustifolia, *L.*, V., VII. Of more restricted distribution than the last, but where it does occur it is usually in greater abundance and covers a considerable area.

Sparganium ramosum, *Huds.*, I., II., III., V., VI., VII. More abundant in VII. than elsewhere, chiefly on the rich, boggy margins of lowland lochs. Dwarf varieties occur as well as the large normal form.

Sparganium simplex, *Huds.*, V., VII. In similar situations to the last species, but usually much less abundant. Weak forms with elongated floating leaves also occur, usually in a foot or so of water. The var. longissimum, *Fries*, occurs at Loch Fitty.

Sparganium natans, *L.*, I., IV., V., VI., VII. Rather frequent in I. and IV.; scarce elsewhere. Chiefly in peaty lochs of but moderate elevation.

Sparganium minimum, *Fries*, I., IV., VI. Abundant in Area I., but in the other districts it is generally scarce and mostly confined to the hill lochs. A terrestrial form with leaves and inflorescences only a few inches high occurs at the margin of hill lochs in Area I. This small terrestrial form seems to be a reversion from the aquatic form towards a terrestrial type which was probably the habit of the ancestral stock. It seems to me that the most degenerate form of S. minimum and the most robust condition of S. ramosum are connected by numerous intermediates. Perhaps experimental culture, on the right lines, with S. ramosum would produce all the others.

LEMNACEÆ

Lemna trisulca, *L.*, VII. Rare in the lochs, and only in those well sheltered by trees, with luxuriant marginal vegetation, and non-peaty water.

Lemna minor, *L.*, VII. Distributed as above, but more frequently met with in the lochs. It is a common plant in ditches, etc., in all Areas below about 500 feet elevation.

POTAMOGETONACEÆ

Zannichellia palustris, *L.*, var. brachystemon, *Gay*, VII. Rare in the lochs, as a rule, but extremely abundant in Kilconquhar Loch.

Potamogeton natans, *L.*, I., II., III., IV., V., VI., VII. Abundant everywhere. The typical form occurs most plentifully in non-peaty lowland lochs. In peaty water it frequently becomes reduced, and then resembles forms of P. polygonifolius, although the two can usually be distinguished by characters exhibited by leaf, fruit, etc.

Potamogeton polygonifolius, *Pourr.*, I., IV., V., VI., VII. Abundant, particularly in peaty water. It varies greatly, and the typical form is usually less abundant than the form approaching P. natans. In the opposite direction of variation is a form which is very abundant in Loch Recar and the adjoining district (Area IV.). This is a very distinct variety, with elongated, rather pellucid leaves that are beautifully netted near the midrib, known as var. pseudo-fluitans, *Syme*.

Potamogeton rufescens, *Schrad.*, V., VI., VII. Sometimes abundant, but not a common species. The variety spathulifolius, *Fischer*, occurs in Black Loch (Area VII.).

Potamogeton heterophyllus, *Schreb.*, III., V., VII. In lowland lakes, but not a common lake plant, although extremely abundant in Loch Cran (Area III.).

Potamogeton lucens, *L.*, I., II., IV., V., VI., VII. Frequently abundant; the very large forms are usually in non-peaty lochs.

Potamogeton Zizii, *Koch*, IV., VI., VII. Sometimes very abundant, especially in Area VII.

Potamogeton crispus, *L.*, I., VI., VII. Not a common species, nor often in abundance. At White Loch, Castle Kennedy (Area VI.), and in other lochs near it, a beautiful form occurs, having wide, bright-red midribs to the leaves.

Potamogeton perfoliatus, *L.*, I., II., IV., VI., VII. Frequent, and sometimes abundant.

Potamogeton prælongus, *Wulf.*, I., IV., V., VI., VII. A deep-water species (6–20 feet). Scarce in Area I., more frequent in the other districts, but seldom very abundant.

Potamogeton Friesii, *Rupr.*, V. Only in Carlingwark Loch.

Potamogeton pusillus, *L.*, I., II., IV., V., VI., VII. Scarce in Area I., frequent in the other districts. The narrow-leaved form—var. tenuissimus, *M. & K.*—occurs occasionally in rather deep water.

Potamogeton obtusifolius, *Mert. & Koch*, II., V., VI., VII. Sometimes abundant. At Barlockhart Loch a dwarf bushy form 6–8 inches long occurred in shallow water, normal forms being abundant in the deeper water. The var. fluvialis, *Lange & Mort.*, occurs in deep water at Burntisland Reservoir, Lismore, etc.

Potamogeton filiformis, *Pers.*, II., VII. Frequently abundant, particularly so at Loch Fitty, where, in some places, the ripe fruits of this plant, with those of P. pusillus, washed up on the shore formed a considerable stratum.

Potamogeton flabellatus, *Bab.*, VII. Very abundant in Town Loch, Dunfermline.

Potamogeton pectinatus, *L.*, VII. Scarce. [VI., rare. Ravenstone Loch, near Sorbie.—J. M'A.] It is abundant in Duddingston Loch, near Edinburgh.

Mr A. Bennett kindly examined a number of difficult forms of Potamogeton for me.

CYPERACEÆ

Schœnus nigricans, *L.*, VI. About the peaty shores of lochs; not common, nor often abundant. [Frequent in damp places along the seashore of Wigtown.—J. M'A.]

Cladium Mariscus, *Br.*, VI. Very abundant about lochs in the Mochrum district. On Anabaglish Moss several small lochans are entirely surrounded by it.

Rhynchospora alba, *Vahl*, IV., VI. Sometimes abundant on shores of boggy peat. A very common moorland plant in these Areas.

Heleocharis palustris, *Br.*, I., II., III., IV., V., VI., VII. Ubiquitous and variable, sometimes 3 feet high; at other places, where exposed to wind, only a few inches high. One such dwarf form, with short, stout, very scaly rhizomes and few flowering stems, which were about 4 inches high, was overgrowing an exposed sandy shore at Loch Grennoch. On a sandbank at Loch Ness there was a form in which the rhizome had discarded the diageotropic habit and assumed negative geotropism in order that it might not be buried too deeply by the accumulating sand.

Heleocharis multicaulis, *Sm.*, IV., V., VI. Sometimes abundant in the more or less peaty lochs; leaves often floating on the surface, and occasionally viviparous at the extremities.

Heleocharis acicularis, *Sm.*, IV., VI., VII. Not a common plant, but occasionally abundant. It forms a sward on the wet sandy or muddy shores of lochs, and enters the water to a depth of about a foot; sometimes, however, to a depth of 3 or 4 feet, in which case the plants are much elongated.

Scirpus fluitans, *L.*, IV., VI. Common in the peaty lochs of these Areas, and sometimes very abundant.

Scirpus setaceus, *L.*, VII. On sandy shores; scarce.

Scirpus lacustris, *L.*, I., II., III., IV., V., VI., VII. Widely distributed and abundant in either peaty or non-peaty lochs. I have seen the stems 14 feet long—6 feet above the surface of water 8 feet deep. The long, linear, grass-like leaves I have only seen in water 3–8 feet deep.

Eriophorum vaginatum, *L.*, I., IV., VI., VII. Sometimes upon the peaty shores of hill lochs, particularly in Area I.

Eriophorum polystachion, *L.*, I., II., IV., V., VI., VII. More frequent than the last-mentioned, especially upon the more or less peaty shores of lowland lakes; less abundant in the mountains.

Carex dioica, *L.*, I. Shores of mountain lochs; not common.

Carex elata, *All.*, I. A carpeting form with diageotropic rhizomes in wet places, and a cæspitose form with negative geotropic rhizomes forming tussocks in water 2 or 3 feet deep. Inchnacardoch Bay, Loch Ness.

Carex disticha, *Huds.*, VII. On sandy-muddy shores; scarce at the lochs. [In meadows at the head of Loch Ken and near Carlingwark Loch.—J. M'A.]

Carex paniculata, *L.*, VII. Forms large tussocks and occupies a considerable area of deep bog at the west end of Otterston Loch. [VI., Dowalton Loch.—J. M'A.].

Carex aquatilis, *Wahl.*, I., II., IV., VII. Both the small and the large lowland forms (*elatior*, *Bab.*) are sometimes very abundant; at the head of Loch Ken specimens over 6 feet high were observed.

Carex Goodenovii, *Gay*, I., II., IV., V., VI., VII. Widely distributed and often very abundant about the shores of both lowland and sub-alpine lochs; on drier parts of the shores of the latter very dwarf forms are frequent.

Carex flava, *L.*, I., III., IV., V., VI., VII. The type and its varieties are frequent upon the shores of lochs, but seldom in abundance.

Carex flacca, *Schreb.*, II., IV., VII. Not uncommon; chiefly about lowland lochs, where it is occasionally very abundant. Tall and dwarf specimens occur.

Carex flacca, *Schreb.*, var. stictocarpa, *Druce*, III., IV., V., VI., VII. Scattered specimens are frequent, but it seldom occurs in any abundance.

Carex binervis, *Sm.*, I., IV., VI. On boggy, peaty shores; usually scarce.

Carex filiformis, *L.*, I., IV., V., VI. Frequent and abundant at the margins of alpine and sub-alpine lochs, where it is sometimes the only abundant species of this genus, and takes the place of C. rostrata.

Carex hirta, *L.*, VII. Not general about lochs, but it grows in abundance on the exposed sandy shores of Loch Leven, where, in common with several other plants, it assumes a dwarf habit, growing only from 4 to 8 inches out of the sand. It grows there much after the manner of Carex arenaria on the sandy seashore, and, like it, binds the sand with its long scaly rhizomes.

Carex rostrata, *Stokes*, I., II., III., IV., V., VI., VII. Probably the most abundant and dominant plant of all at the margins of lochs, in either peaty or non-peaty water up to 24 inches deep. By its large and rapid growth, a considerable amount of detritus is thrown down annually; it is therefore a most important plant in converting shallow places about lochs into *terra firma*.

Carex vesicaria, *L.*, I., IV. Similar in habit to C. rostrata, but it is not so robust and requires less water. It is not nearly so common as C. rostrata, although occasionally it is very abundant.

Carex acutiformis, *Ehrh.*, V. As a constituent of a loch flora I have only observed this plant at Carlingwark Loch.

GRAMINEÆ

Phalaris arundinacea, *L.*, I., IV., V., VI., VII. Scarce in Area I. In the other areas it is rather common about the margins of the lowland lochs.

Phragmites communis, *Trin.*, I., II., III., IV., V., VI., VII. A very dominant and abundant species in lowland or highland, peaty or non-peaty lochs. On rich, muddy shores of wind-sheltered lochs it attains great luxuriance, often being 8 or 10 feet high in such situations, and overgrowing large areas.

Deschampsia cæspitosa, *Beauv.*, I., IV., V., VI., VII. A very usual member of the shore flora of lochs, but generally in small quantities.

Glyceria fluitans, *Br.*, I., II., III., IV., V., VI., VII. Widely distributed, but seldom in great abundance. The leaves of aquatic forms float on the surface, whilst those of terrestrial forms are erect in the air.

Glyceria aquatica, *Wahlb.*, V., VII. Seldom seen at the lochs, but occasionally it does occur in great abundance; instance Carlingwark Loch, Lindores Loch, etc.

Alopecurus geniculatus, *L.*, is very abundant on the sandy-muddy shore of Town Loch, Dunfermline.

Agrostis vulgaris, *With.*, is very abundant at the same place and also at Lindores Loch. Small patches or isolated specimens of these two grasses, with other terrestrial species, are frequently found mixed with the semi-aquatic vegetation of the littoral. Frequently too the grass sward of a moor or meadow adjoining a loch enters the water, and, contrariwise, aquatics such as Littorella lacustris leave the water and compete for *terra firma* against the land plants. Aquatic and terrestrial zones of vegetation, in such cases, are undeterminable.

EQUISETACEÆ

Equisetum limosum, *L.*, I., II., III., IV., V., VI., VII. This is another very abundant species; large associations occur at the margins of lochs of all descriptions. It prefers deeper water than Carex rostrata; sometimes it occurs even in water 5 feet deep. When the two are growing in the same locality, which is very usual, the colonies are always distinct from one another, with the Equisetum out in the deeper water.

Equisetum arvense, *L.*, and E. palustre, *L.*, are occasionally found overgrowing sandy or stony shores, in which case, unless sheltered by other vegetation, they are always prostrate and dwarfed, and sometimes form a sward.

MARSILEACEÆ

Pilularia globulifera, *L.*, VI. Rare, but occasionally very abundant —at Loch Dernaglar, for example.

LYCOPODIACEÆ

Isoetes lacustris, *L.*, I., IV., V., VI. Very general in the peaty hill lochs, but neither so abundant nor so variable in form in the southern Areas as in Area I. It usually forms a bottom carpet at depths of from 2 to 20 feet. In some lochs of the Ness Area these specimens are about 4 or 5 inches long, with stout, erect leaves, forming stiff little plants. In other places, apparently under similar conditions but with darker peaty water, the leaves are 18 inches long, weak and recurved.

CHARACEÆ

Messrs H. and J. Groves most kindly gave me the benefit of their unrivalled knowledge of these plants, and identified a number of difficult forms. On the whole, the Characeæ are less abundant in Areas IV.–VI. than in Areas I.–III.; they are also abundant in VII.

Nitella opaca, *Ag.*, I., IV., V., VI., VII. Generally distributed in peaty lochs. In Area I. it occurs at a greater depth, namely 30 feet, than any other plant, save Fontinalis antipyretica. In Areas IV.–VII. I have never dredged it from a greater depth than about 16 feet, nor, indeed, have I found any of the higher plants at a much greater depth in these Areas. Reasons for this will be given on subsequent pages. Slender forms, approaching var. attenuata, *H. & J. G.*, occur in Loch Ness, and others of that Area.

Nitella translucens, *Ag.*, I., VI. Rare; only observed at Loch Meiklie in 8–10 feet of water, and at similar depths in the Mochrum district. A very large form in a barren state, extremely like translucens, was referred by Messrs Groves to N. flexilis, or N. opaca. It was abundant in Loch Ken and Woodhall Loch, at 6–8 feet deep.

Chara aspera, *Willd.*, II., III., V., VII. Frequently abundant in lowland non-peaty lochs, or in lochs that receive the drainage of villages. Sometimes it is incrusted with lime. In some lochs this plant occurs in prodigious quantity. In Loch

Leven, for example, hundreds of acres of the bottom are covered by it. In that loch it occurs at depths of from 1 to 15 feet, but is most abundant at 4 to 8 feet deep. The varieties of this species are also common, and frequently occur with the type—vars. subinermis, *Kütz.*, and desmacantha, *H. & J. G.*, being the most usual.

Chara fragilis. *Desv.*, I., II., IV., V., VI., VII. Occurs in both peaty and non-peaty waters. In the former case it is usually free of lime; in the latter it is generally more or less incrusted with that substance. The common form in peaty lochs is the var. delicatula, *Braun.* Both forms are occasionally very abundant.

Chara vulgaris, *L.*, VII. This does not appear to be a common form in the lochs, but it occurs occasionally—at Loch Leven, for example.

Chara hispida, *L.*, var. rudis, *Braun*, II., VII. In the former Area this occurs as a large coarse plant at depths of 25–35 feet, and is much incrusted with lime. In the latter Area it occurs in shallower water, is much smaller, and but slightly incrusted.

Chara contraria, *A. Br.*, IV., VII. Regarding a slightly incrusted form in shallow water at Loch Whinyeon, Messrs Groves write:—"A very interesting little plant immediately between C. contraria and C. vulgaris, but we think it best placed under the former."

The Bryophyta often form a very conspicuous portion of the shore flora of lochs in Areas IV. and VI.—very much more so than in Areas I.-III. By instituting a careful search for these plants a very long list might be arranged, particularly in Areas IV. and VI.

SPHAGNACEÆ

Sphagnum intermedium, *Hoffm.*, IV., VI., VII. On boggy shores of peaty lochs.

Sphagnum cymbifolium, *Ehrh.*, I., IV., VI., VII. On boggy shores of peaty lochs.

Sphagnum acutifolium, *Ehrh.*, I., IV., V., VI., VII. One or other of its numerous forms is common on boggy shores of peaty lochs.

Sphagnum cuspidatum, *Ehrh.*, I., IV., VI. Frequent in the water in bays, etc., of small peaty lochs, as well as on their boggy shores. The variety plumosum is less frequent.

Sphagnum subsecundum, *Nees.*, I., IV., VI. In similar habitats to the last, but less frequent; sometimes in rather deep water. The variety viride, *Boul.*, occurs in some of the lochs of Area I., but is scarce.

POLYTRICHACEÆ

Polytrichum commune, *L.* This common moorland moss is occasionally plentiful on peaty shores.

Catharinea undulata, *Web. & Mohr*, IV. A common moss, but it rarely occurs in any abundance at the lochs, it being a more or less terrestrial plant. At Loch Minnoch, however, submersed rocks were abundantly clothed with an aquatic form of it.

DICRANACEÆ

Dichodontium pellucidum, *Schp.*, IV., VI. Common on rocks of the shores of lochs in hilly districts.

Blindia acuta, *B. & S.*, I., IV., V., VII. On wet or submerged rocks; common about the shores of hill lochs.

Dicranella squarrosa, *Schp.*, IV. Often abundant on the wet, boggy shores of hill lochs. D. heteromalla, *Schp.*, is also frequent, but on drier ground.

Dicranum fuscescens, *Turn.*, IV. Rocks on the shores of hill lochs; common.

Dicranum Scottianum, *Turn.*, IV. As above, but less common.

FISSIDENTACEÆ

Fissidens adiantoides, *Hedw.*, I., IV. Often abundant in wet places on rocky shores.

GRIMMIACEÆ

Grimmia apocarpa, *Hedw.*, IV., VI. Common on the dry parts of rocks about the shores.

Grimmia apocarpa, *Hedw.*, var. rivularis, *Web. & Mohr*, IV., VI. Frequently abundant on wet and submersed rocks, occasionally down to 5 or 6 feet deep. In other areas it is scarce at the lochs.

Rhacomitrium lanuginosum, *Brid.*, IV. Often a conspicuous object in this area, upon the rocks of the shores.

Rhacomitrium heterostichum, *Brid.*, IV. Various forms of it are common in similar situations to the last.

Rhacomitrium aciculare, *Brid.*, I., IV., V., VII. Frequent upon wet and submersed rocks; but sometimes only near the embouchures of burns.

Rhacomitrium protensum, *Braun*, IV. Sometimes abundant on wet rocks. When luxuriant, as at Loch Dungeon, it has a very pleasing appearance.

Hedwigia ciliata, *Ehrh.*, IV. The type and the var. leucophæa, *B. & S.*, frequently cover the syenite rocks that abound upon the shores, or crop out of the water, as islands, in the lochs of this Area.

TORTULACEÆ

Trichostomum tortuosum, *Dixon*, IV. Occasionally abundant on the littoral rocks of the hill lochs.

ORTHOTRICHACEÆ

Orthotrichum rupestre, *Schleich.*, IV., VI. A common moss on rocks about the shores of lochs in hilly districts.

MEESIACEÆ

Aulacomnium palustre, *Schwaeg.* In wet places about shores, or even in the water; frequent in all the areas.

BARTRAMIACEÆ

Philonotis fontana, *Brid.*, I., IV. On wet shores or at the margin of the water, common in IV., but occurs in other Areas sparingly. P. calcarea, *Schp.*, occurs on the boggy shore at the south-east end of Loch Leven.

Breutelia arcuata, *Schp.*, IV. On rocks; generally scarce at loch shores, but it grows in magnificent luxuriance at Loch Dungeon.

BRYACEÆ

Several species of Bryum occur, but seldom in abundance. B. alpinum, *Huds.*, is sometimes noticeable on rocks of the hill lochs in Area IV. B. bimum, *Schreb.*, occurs in scattered patches on wet or boggy shores, here and there, in all the Areas; similarly does B. pallens, *Sw.* At Burntisland Reservoir a curious form of the last-mentioned was very abundant in water to about 18 inches deep, on the clayey bottom. Mr H. N. Dixon, to whom I submitted specimens, replied as follows:—"Mr Nicholson, to whom I sent the Burntisland Reservoir Bryum, agrees with me that while, at first sight, it resembles B. neodamense, it is really an altered form of B. pallens."

Mnium punctatum, *L.*, IV. Frequently abundant on wet, somewhat sandy shores; also in the other Areas, but seldom in any abundance at the lochs.

FONTINALACEÆ

Fontinalis antipyretica, *L.*, I., II., IV., V., VI., VII. In Area I. it is very abundant everywhere, from half-submerged rocks to a depth of 30 feet. In II. it is less abundant in shallow water, but an attenuated form is common in deep water, even to a depth of 40 feet. In Areas IV.–VII. I have not obtained it from a greater depth than 10 feet. In V. and VII. it is less common than elsewhere.

Fontinalis squamosa, *L.*, IV., VI. Sometimes plentiful, but not a common moss in the lochs.

HOOKERIACEÆ

Pterygophyllum lucens, *Brid.*, IV. Abundant about the wet shores of the hill lochs, mostly on the soil.

LEUCODONTACEÆ

Pterogonium gracile, *Swartz*, IV. On shore rocks; frequent and abundant at lochs amongst the hills.

LESKEACEÆ

Heterocladium heteropterum, *B. & S.*, IV. This delicate species is seldom found at the lochs. It was, however, very abundant as a submersed aquatic at Loch Grennoch, even to a depth of 10 feet.

HYPNACEÆ

Climacium dendroides, *Web. & Mohr*, V., VII. Occasionally abundant on boggy shores.

Hyocomium flagellare, *B. & S.*, IV. Frequent on shore rocks.

Brachythecium rivulare, *B. & S.*, I., IV., VI., VII. On dry and submersed rocks, frequent.

Eurhynchium rusciforme, *Milde*, I., IV. In habitats similar to the last. It is also common in the other Areas, but is scarce at the lochs. At the south end of Loch Doon it was very abundant at a depth of 3 to 5 feet, occurring there with Fontinalis antipyretica.

Hypnum riparium, *L.*, VII. Not common at lochs, but it is abundant on stones at Burntisland Reservoir.

Hypnum stellatum, *Schreb.*, IV., V., VI., VII. Often abundant on boggy shores.

Hypnum fluitans, *L.*, I., IV., VI., VII. In Area I. it is rather scarce about the shores of lowland lochs. In the other Areas it is common about the hill lochs.

Hypnum uncinatum, *Hedw.*, I., IV. On rocks of the shores of hill lochs.

Hypnum revolvens, *Swartz*, IV., VII. On wet shores, chiefly of the hill lochs.

Hypnum commutatum, *Hedw.*, IV., VII. Remarks similar to the last.

Hypnum falcatum, *Brid.*, I., IV., VII. In habitats similar to the two preceding species.

Hypnum ochraceum, *Turn.*, I. About the shores of mountain lochs; not abundant.

Hypnum vernicosum, *Lindb.*, IV. Common at Loch Minnoch.

Hypnum cupressiforme, *L.*, IV. Forms of this common moss frequently cover rocks on the shores in this Area. In the other Areas it is much less abundant at the lochs.

Hypnum scorpioides, *L.*, I., II., IV., VI., VII. Mostly about the wet or boggy shores of hill lochs. Scarce at the lochs of Areas I. and VII. In Area II. a very large form of this moss was abundant about the rhizomes of Scirpus lacustris at depths of 3 to 5 feet.

Hypnum scorpioides, *L.*, forma ad var. miquelonense, *Ren. & Card.*, proxime accedens., I. In Lochs Ruthven, Ness, and Uanagan, in water 5 to 10 feet deep.

Hypnum stramineum, *Dicks.*, I., VII. Abundant in shallow places about lochs in Portclair Forest, also at Loch Fitty; scarce elsewhere. [IV., V., J. M'A.]

Hypnum trifarium, *Web. & Mohr*, I. In some of the lochs in Portclair Forest.

Hypnum cuspidatum, *L.*, I., IV., V., VI., VII. Common in marshy places about lochs; sometimes in great abundance, and frequently growing in the water. It is less abundant in I. than in the other Areas noted.

Hylocomium squarrosum, *B. & S.*, I., II., III., IV., V., VI., VII. A common and often abundant moss on wet shores, chiefly in lowland districts, in all the Areas; particularly in IV. and VI.

JUBULEÆ

Frullania tamarisci, *Dum.*, IV. Frequently covering damp rocks by the shores of the higher lochs.

PORELLEÆ

Pleurozia cochleariformis, *Dum.*, IV. Occasionally conspicuous on boggy shores of the higher lochs.

PTILIDEÆ

Anthelia julacea, *Dum.*, IV. Occasionally its grey-green tufted patches form a conspicuous object on the wet sandy or peaty shores of the mountain lochs.

SCAPANIOIDEÆ

Scapania undulata, *Dum.*, I., IV., VI. Abundant on rocks and stones at the margins of hill lochs, both submersed and out of the water. It also occurs in VII., but rarely.

Diplophyllum albicans, *Dum.*, IV. Sometimes covers the shore rocks of the hill lochs.

EPIGONIANTHEÆ

Chiloscyphus polyanthos, *Dum.*, V. Occasionally abundant on wet shores, and in the pools.

Mylia Taylori, *Gr. & Benn.*, IV. On wet shore rocks, or on wet sandy shores. Large patches of it are occasionally abundant at the hill lochs.

Nardia compressa, *Gr. & Benn.*, I., IV. Abundant on wet and submersed rocks, chiefly at the higher lochs. Sometimes a considerable area of submersed rocks and stones, to a depth of 3 feet, is covered with a dense carpet of this hepatic: instance Lochs Enoch, Dungeon, etc.

Nardia emarginata, *Ehrh.*, I., IV. On wet rocks and shores, and often in the water; rather less abundant than the last-mentioned. Chiefly at the hill lochs.

Nardia scalaris, *Gr. & Benn.*, IV. On wet sandy-peaty shores of hill lochs; often abundant.

The following species are frequently found covering wet places about lochs, particularly on shady banks, under rocks, etc., in all the Areas, especially IV.:—Pellia calycina (*Tayl.*); P. epiphylla, *Lindb.*; Conocephalus conicus, *Dum.*; and Marchantia polymorpha, *L.* The last-mentioned is often found in the water of bogs as well as in drier places.

Several species of Jungermannia are met with on the shores of the more elevated lochs, but always in small quantities.

Amongst the mountains of Area IV. many lochs are bordered more or less by great rocks which are frequently covered in a most prolific manner with masses of lichens. A description of the flora of these lochs would be incomplete were it not, under such circumstances, to notice the most predominant and conspicuous species of these lichens. They are as follows:—Platysma glaucum, *Nyl.*; Cetraria aculeata, *Fr.*; C. muricata, *Ach.*; Parmelia lanata, *Wallr.*; P. omphalodes, *L.*; Alectoria jubata, *Nyl.*; Lecanora tartarea, *Ach.*; Sphærophoron coralloides, *Pers.*; Lecidea geographica, *Schær.*

ALGÆ

A few dominant species that were noticed:—

Batrachospermum moniliforme, *Roth*, I., IV. Abundant; very scarce in the other Areas.

Batrachospermum vagum, *Roth.* I. Scarce. IV., VI. Frequent; very scarce in the other Areas.

Œdogonium capillare, *L.*, III. Only noticed in abundance here.

Enteromorpha intestinalis, *Link*, III., VII. Particularly plentiful in Kilconquhar Loch and Loch Fitty.

Ulothrix æqualis, *Kütz.*, and its var. catæniformis, *Rabenh.* In all the Areas, but particularly in IV.

Conferva fontinalis, *Berk.* [= Rhizoclonium hieroglyphicum, *Kütz.*]. Very general in lochs that receive drainage from villages.

Cladophora fracta, *Kütz.*, II., VII. Occasionally very abundant.

Cladophora crispata, *Roth.*, VII. Occasionally abundant.

Cladophora flavescens, *Ag.*, V., VII. Sometimes very abundant in lochs that receive the drainage of villages.

Cladophora canalicularis, *Roth.*, VI., VII. Abundant; less so in the other Areas. It covers stones and rocks about the shores of lochs that receive the drainage of villages and farms. It is often covered with a prodigious quantity of diatoms.

Cladophora glomerata, *Kütz.* Very abundant in some lochs of Areas IV. and VI., covering stones and rocks from the margin to 7 feet deep.

Mougeotia sp. Sometimes very abundant in I. and IV.

Zygogonium ericetorum, *De Bary*, I., IV. Often very abundant in water near the shores of the hill lochs.

Zygnema Vaucherii, *Ag.*, I., II., IV., VI. Frequent.

Spirogyra crassa, *Kütz.*, III. Only noticed in abundance here.

Porphyridium cruentum, *Näg.*, VI. Wet mud at Barhapple Loch, exposed through drought, was in places coloured red by this organism.

Glœotrichia Pisum, *Thur.*, VI. Occurs in such extreme abundance as a plankton organism in Soulseat Loch that the water, in some of the little creeks, is of the consistency of liquid mud.

Anabæna circinalis, *Rabenh.*, VII. The water of Kinghorn Loch, in places, had the appearance of pale green paint, due to the vast quantity of this organism.

Melosira granulata, *Ralfs.*, VI. Occurs, as a plankton organism, in White Loch, Castle Kennedy, in such abundance that the discoloration of the water (p. 243) is, in part, due to it.

Dickieia and similar gelatinous Diatomaceæ, I., IV. Sometimes abundant at the margins of the hill lochs. Other diatoms, of course, abound everywhere.

I have frequently found submersed plants of the higher orders injured by the luxuriant growth of filamentous Algæ. In Loch Skerrow and Loch Grennoch, for example, quantities of Scapania undulata were in a defunct condition through being overgrown with Ulothrix æqualis, Batrachospermum vagum, Binuclearia tatrana, etc.

In Area I. many moor and hill plants, that are either scarce or entirely absent in the south, grow in great profusion. The following may be mentioned as being conspicuous by their frequent abundance :—Antennaria dioica, Arctostaphylos Uva-Ursi, A. alpina, Betula nana, Cnicus heterophyllus, Cornus suecica, Rubus Chamæmorus, Cystopteris fragilis, Drosera intermedia, Empetrum nigrum, Galium boreale, Trientalis europæa, etc. In the district of New Galloway, and, in fact, throughout the country for miles around, there are a few abundant plants that form a characteristic feature of this neighbourhood. They are as follows:—Jasione montana and Lepidium heterophyllum in dry places, Carum verticillatum and Œnanthe crocata in damp and wet places.

In the original publications a detailed list of plants is given for each loch or series of lochs. In this epitome, however, such local lists have been omitted. The two hundred and thirty-four illustrations, with their descriptive legends, that accompany the original papers have also been left out, but a few new ones have been inserted here.

The following comparative table has been arranged in order to show at a glance the most conspicuous and dominant plants (*i.e.* those forming definite associations) of peaty and non-peaty lochs, together with the positions they usually occupy therein. The plants may be divided into seven groups (see below), and those in each group are so arranged that the species inhabiting the driest ground or the shallowest water are placed first, and those occupying the deepest water last; the whole table being kept as nearly as possible in the same order. The figures following the species indicate in feet the average depths at which they occur, a medium between the two extremes being the most usual habitat.

COMPARATIVE TABLE

Peaty Moorland Lochs with Clear Water	Non-Peaty Lowland Lochs with Clear Water
1. *The Drier Marsh Species*	
Bryophytes on shore rocks often abundant.	Bryophytes on shore rocks usually scarce.
Deschampsia cæspitosa.	Gnaphalium uliginosum.
Juncus effusus.	Deschampsia cæspitosa.
Juncus bufonius.	Carex hirta.
Mentha sativa.	Juncus conglomeratus.
Eriophorum polystachion.	Spiræa Ulmaria.
Eriophorum vaginatum.	Juncus effusus.
Phalaris arundinacea.	Juncus bufonius.
Juncus supinus.	Mentha sativa.
Ranunculus Flammula.	Phalaris arundinacea.
	Carex disticha.
	Ranunculus Flammula.
2. *Marsh Species with their Bases usually in Semi-Liquid Mud, or even in Water*	
Various bog mosses, including species of Sphagnum and Polytrichum.	Various bog mosses, excluding species of Sphagnum and Polytrichum.
Caltha palustris.	Caltha palustris.
Carex Goodenovii.	Carex Goodenovii.
Carex vesicaria.	Mentha aquatica.
Carex aquatilis (dwarf form).	Iris Pseud-acorus.
Juncus articulatus, shore–l.	Ranunculus Lingua.
Comarum palustre, shore–l.	Alisma Plantago.
Hypericum elodes, shore–l.	Sparganium ramosum, shore–l.
	Juncus articulatus, shore–l.
	Carex paniculata, shore–l.
	Typha latifolia, shore–l
	Glyceria aquatica, shore–l.
	Comarum palustre, shore–l.
	Sparganium simplex, shore–l.
	Epilobium hirsutum, shore–l.

3. *Semi-Aquatic Species that send up from the Water a strong Aerial Flowering Stem, but without special Submerged or Floating Leaves*

Peaty Moorland Lochs—*contd.*	Non-Peaty Lowland Lochs—*contd.*
Menyanthes trifoliata, shore–1.	Menyanthes trifoliata, shore–1.
Heleocharis palustris, shore–1½.	Heleocharis palustris, shore–1½.
Carex rostrata, shore–2.	Typha angustifolia, shore–1½.
Carex filiformis, shore–2.	Carex flacca, shore–1½.
Carex elata, shore–2.	Carex rostrata, shore–2.
Cladium Mariscus, shore–2.	Carex filiformis, shore–2.
Phragmites communis, shore–3.	Carex aquatilis (elatior), shore–2.
Equisetum limosum, 1–5.	Phragmites communis, shore–3.
	Equisetum limosum, 1–5.

4. *Semi-Aquatic Species that send up from the Water a strong Aerial Flowering Stem, having also Submerged or Floating Leaves that often differ from the Aerial ones*

Peaty Moorland Lochs	Non-Peaty Lowland Lochs
Glyceria fluitans, ½–1½.	Glyceria fluitans, ½–1½.
Heleocharis multicaulis, ½–1½.	Hippuris vulgaris, 1–6.
Sparganium natans, 1–3.	Scirpus lacustris, 2–7.
Scirpus lacustris, 2–7.	

5. *Aquatic Species that grow up into the Water from the Bottom more than a foot in height, and usually with at least some Leaves that reach the surface and float there*

Peaty Moorland Lochs	Non-Peaty Lowland Lochs
Species of the following genera of Algæ are characteristic of peaty lochs; they cover rocks, other submerged plants, etc., or more rarely float in the water of bays, etc:—Ulothrix, Mougeotia, Zygogonium, Zygnema, and Batrachospermum.	The following genera of Algæ are characteristic of lowland lochs, and masses of them often float at the surface:—Enteromorpha, Cladophora, Spirogyra, and Œdogonium.
Polygonum amphibium, shore–4.	Polygonum amphibium, shore–4.
Apium inundatum, 1–4.	Apium inundatum, 1–4.
Potamogeton rufescens, 2–10.	Ranunculus peltatus, etc., 1–7.
Castalia speciosa, 2–10.	Potamogeton heterophyllus, 1–10.
Nymphæa lutea, 2–12.	Castalia speciosa, 2–10.
Potamogeton polygonifolius, 2–12.	Nymphæa lutea, 2–12.
Potamogeton natans, 2–20.	Potamogeton polygonifolius, 2–12.
Nymphæa pumila, 7–15.	Potamogeton natans, 2–20.

PEATY MOORLAND LOCHS—*contd.*	NON-PEATY LOWLAND LOCHS—*contd.*

6. *Aquatic Species that grow up into the Water from the Bottom usually more than a foot in height, but never or rarely producing Leaves that float on the surface*

Peaty Moorland Lochs	Non-Peaty Lowland Lochs
Bryophytes on submerged rocks often abundant, especially the following species:—Blindia acuta, Eurhynchium rusciforme, Fontinalis squammosa, F. antipyretica, Scapania undulata, Nardia emarginata, N. compressa, etc.	Bryophytes on submerged rocks almost absent, but the following species sometimes occur:—Blindia acuta, Eurhynchium rusciforme, Fontinalis antipyretica, etc.
Utricularia intermedia, ½–3.	Ranunculus circinatus, etc., 2–8.
Scirpus fluitans, 1–5.	Zannichellia palustris, 2–8.
Callitriche hamulata, 1–10.	Potamogeton flabellatus, 2–8.
Juncus fluitans, 1–10.	Potamogeton pectinatus, 2–8.
Myriophyllum alterniflorum, 1–10.	Potamogeton filiformis, 2–8.
Potamogeton pusillus, 2–10.	Myriophyllum alterniflorum, 1–10.
Utricularia vulgaris, 1–15.	Callitriche autumnalis, 2–10.
Potamogeton Zizii, 3–15.	Potamogeton Friesii, 2–10.
Potamogeton lucens, 3–20.	Myriophyllum spicatum, 2–10.
Potamogeton prælongus, 5–20.	Ceratophyllum demersum, 2–10.
Potamogeton perfoliatus, 5–20.	Nitella translucens, 2–10.
Chara fragilis, v. delicatula, 2–25.	Anacharis Alsinastrum, 2–10.
Nitella opaca, 3–30.	Potamogeton obtusifolius, 2–10.
Fontinalis antipyretica, shore–35.	Utricularia vulgaris, 1–15.
	Chara fragilis, 1–15.
	Potamogeton pusillus, 2–20.
	Potamogeton crispus, 2–20.
	Potamogeton Zizii, 3–20.
	Potamogeton lucens, 3–20.
	Potamogeton prælongus, 5–20.
	Potamogeton perfoliatus, 5–20.
	Chara fragilis, v. delicatula, 2–25.
	Chara aspera, 2–25.
	Nitella opaca, 3–30.
	Chara hispida, v. rudis, 10–35.
	Fontinalis antipyretica, shore–40.

7. *Aquatic Bottom-carpeting Species, usually but a few inches high (excluding flowering stalks)*

Peaty Moorland Lochs	Non-Peaty Lowland Lochs
Heleocharis acicularis, shore–4.	Heleocharis acicularis, shore–4.
Subularia aquatica, shore–4.	Littorella lacustris, shore–5.
Littorella lacustris, shore–5.	Elatine hexandra, shore–8.
Pilularia globulifera, ½–3.	
Lobelia Dortmanna, ½–6.	
Isoetes lacustris, 2–20.	

PART III.—THE LAKES

Full particulars as to the dimensions, depth, and other physical features of the lakes sounded by the Lake Survey will be found in Vol. II.

Area I

This area is chiefly one of mountain and moor lying in a condition of untamed nature. The only areas of cultivation are either in the glens or on the lower upland slopes; but excepting in the most favourable parts, farming cannot be said to be a very thriving occupation. There is very little sheep-farming, because the hills are required for deer. The only large manufacturing industry is that of the British Aluminium Company at Foyers, which is located there because of a convenient and adequate water supply. A considerable number of the inhabitants find occupation in the rearing of game, as the district is largely devoted to sport. In some places there are plantations of considerable size, but a scientific system of profitable sylviculture is not the general practice, the trees usually having been planted to afford shelter to houses and farms, or for game.

The scenery is frequently very beautiful, as those who have passed by steamer through the Caledonian Canal will admit. The wildest scenery, however, is only to be found amongst the mountains, and these are frequently difficult of access. The dominant moor vegetation usually consists of plants of the orders Ericaceæ and Sphagnaceæ; but in many places this natural vegetation is being destroyed by burning, in order to further the expansion of grasses and grass-like plants which afford food to the numerous deer. In consequence of this natural vegetation the mountains and moors are nearly everywhere covered with peat. The rain-water, therefore, which falls upon the mountains has to percolate through enormous quantities of peat before reaching the lochs, so that their water is, as a rule, brown and peaty. This peat extract has a great influence upon the flora of the lochs, as has been already mentioned. Only in a few districts where there are bands of limestone, such as on the hills north of Glen Urquhart, or where peat is practically absent, are there lochs whose water is not distinctly peaty. In fact, the yellow-brown appearance of the water cannot be overlooked by the most casual observer when passing through the Caledonian Canal, of which Lochs Ness, Oich, and Lochy form the greater part.

We may begin our inspection of the lochs of this area at Loch Ness; thence we pass by way of Loch Oich to some mountain lochs north of Lochs Lochy and Oich. From there we proceed to the lochs lying on the desolate mountains both to the south and north of

Glen Moriston. Crossing the picturesque Glen Urquhart, we visit the sheets of water to the north. Then passing eastwards at the north end of Loch Ness, we inspect a series of lochs on the hills to the east, working our way southwards towards Carn a' Chuilinn, and finishing the tour at Fort Augustus. The original paper contains 102 illustrations of the lochs, etc., of this area.

Loch Ness is the largest fresh-water loch in Scotland; it is 24 miles long by $\frac{3}{4}$ of a mile to 2 miles broad. It is also one of the deepest of the Scottish lakes, and drains an area of nearly 700 square miles. Its surface is 52 feet above sea-level. It is situated in a depression, with mountains rising almost precipitously from its waters on either side, throughout its whole length. At the north-east and south-west ends, however, the land is low-lying and comparatively flat, being, in fact, the strath, or bottom of the valley, known as the Great Glen, that bisects the Highlands from Loch Linnhe to the Moray Firth. The lower slopes of the adjacent mountains are abundantly clothed with forest to the water's edge. This sylvan scenery, associated with the effect produced by other plant formations on the mountains above, combined with occasional crags of grey or red rock boldly projected, gives this superb sheet of water a magnificence of its own that can seldom be surpassed. Abundant and beautiful as is the terrestrial flora, that of the water is extremely scanty; the causes which bring about this paucity have already been mentioned. One may traverse miles of the shores of this lake and find scarcely an aquatic plant, unless it be the lithophilous Bryophyta or Algæ, that defy the erosive power of the waves to remove them from the rocks. The only places in Loch Ness where aquatic plants are abundant are Urquhart Bay, Inchnacardoch Bay, about the south-west portion from Borlum to the railway pier, where the water is comparatively shallow, with a pebbly, sandy, or muddy bottom; also, but more scantily, about the estuaries of the rivers Moriston and Foyers, and in a few small sheltered bays here and there about the lake. Generally the shore is so steep that deep water occurs close to it. Opposite Invermoriston, for example, a depth of 652 feet occurs at 120 yards from the shore. This great depth so near the shore is, of course, exceptional, but it serves as an example to show the impossibility of there being an abundant bottom flora of the higher forms under such circumstances. Owing to the matter held in solution by the water, the photic zone, throughout which there exists sufficient light for the proper development of the higher plants, does not extend in this loch beyond a depth of about 30 feet. It therefore follows that, on account of the steepness of the sides, the limit of depth for the higher plants is reached, as a general rule, within a few feet of the shore. Then it must be remembered that everywhere, except in sheltered bays or creeks, no phanerogams can exist at the bottom within 4 or 5 feet of the surface, on account of the erosive action of the waves; so that there remains a very narrow zone available for such plants, and as a rule none occur. This is a common feature not only of Loch Ness, but of all the large lochs that I have examined.

The sudden rise and fall of the water of Loch Ness, due to its being fed by eight good-sized rivers as well as by about forty burns, yet having but one effluent, must be mentioned as being a further factor antagonistic to the well-being of plants. The records kept by the Canal authorities at Fort Augustus give the maximum rise of 7 feet 4 inches from the lowest in dry periods to the highest in wet weather. A rise of 2 feet within a few hours is quite a usual occurrence. This becomes more comprehensible when it is remembered that a rainfall of $2\frac{1}{4}$ inches means the addition of 100 millions of tons of water to the drainage area, most of which speedily finds its way into the loch. At Loch Mhor there is a rise and fall of 22 feet, caused by artificial agency; the effect of this upon vegetation is there very evident.

At the south-west end of the loch, from Borlum to the embouchure of the river Tarff, the shore consists of gravel and sand, and forms a large high beach. On the crest and rear of this beach there is a considerable flora, ranging, in accordance with the œcological conditions, from xerophilous plants in the more elevated parts to hygrophilous vegetation at a lower level. Behind the beach there is an extensive marsh containing the plants usual to such an environment that are common to the district. Along this beach no semi-aquatic plants occur in the loch, on account of the waves. From the beach the aquatic flora extends over the bottom from about 5 feet to 30 feet deep, the chief plants being Littorella lacustris, Isoetes lacustris, Myriophyllum alterniflorum, Nitella opaca, and Fontinalis antipyretica; an occasional plant of the two last-mentioned may be found even to a depth of 40 feet. The bottom here is mostly of gravel down to 30 or 40 feet; in deeper water mud obtains. The Caledonian Canal entrance into Loch Ness has a luxuriant aquatic flora upon its embankments, but this is almost limited to Lobelia Dortmanna, Juncus fluitans, Callitriche hamulata, and Myriophyllum alterniflorum. From here, past the embouchure of the river Oich to the point beyond the railway pier, the flora is extremely scanty. There is practically no shore; the rocks have occasional patches of Nardia emarginata or Scapania undulata, and are sometimes green with Zygnema. Rounding the point, we enter Inchnacardoch Bay. The water over a considerable area of this bay is less than 20 feet deep, with a sandy or muddy bottom which bears a luxuriant vegetation. The only island of Loch Ness—Cherry

Island—is at the entrance to this bay. It is very small, and is overgrown with dwarf trees. The aquatic flora of the bay, although extremely abundant, is almost restricted to the following species:—Littorella lacustris, Lobelia Dortmanna, Isoetes lacustris, Myriophyllum alterniflorum, Juncus fluitans, Chara fragilis, var. delicatula, Utricularia vulgaris, Nitella opaca, Fontinalis antipyretica, Potamogeton natans, P. lucens, Callitriche hamulata, Sparganium natans, Glyceria fluitans, Polygonum amphibium, Menyanthes trifoliata, Equisetum limosum, Carex rostrata, and a large number of other marsh plants, including Carex elata, which forms tussocks that stand up out of the water, as well as assuming a carpeting habit on drier ground.

Leaving this bay, we meet with scarcely any aquatic plants, except such as may occur in little bays, until Invermoriston is reached. Here again there is a paucity in the variety and quantity of aquatic plants, nothing calling for special remark.

From Invermoriston to Urquhart Bay, a distance of some ten miles, there is nothing in the way of aquatic flora to demand attention. In Urquhart Bay, however, conditions prevail similar to those of Inchnacardoch Bay, the bottom being of firmer sand down to a depth of 20 or 25 feet; but beyond this, mud occurs everywhere. It should be noticed that in Borlum Bay, which receives the full force of easterly gales, the mud deposit on the bottom only begins at depths of from 30 to 40 feet—that is, about 10 feet deeper than in the somewhat sheltered Urquhart Bay, where the vegetation is similar to that of Inchnacardoch Bay, but the marsh plants are more varied in species and grow more luxuriantly. At Urquhart Bay two rivers enter Loch Ness: the Enrick, draining the populous and highly cultivated Glen Urquhart, and the Coiltie, from Balmacaan Forest, which also drains a considerable area of cultivation. The nitrogenous substances and the lime from a district north of Glen Urquhart brought down by these rivers, undoubtedly to a certain extent, extinguish the action of the humic acids over a considerable delta that has been formed by these streams, and upon it a dense vegetation of the marsh and woodland types has developed. The water of the bay, however, owing to the great bulk of the loch, is probably but very little, if at all, modified by the rivers; the similarity of the aquatic vegetation to that of other portions of the loch bears out this remark.

Passing out of Urquhart Bay, there is little more, regarding aquatic plants, to arrest our attention in Loch Ness. At the north-east end of the loch, from Lochend to the lighthouse at the entrance to Loch Dochfour, there is a remarkably large, high, stony beach. During westerly gales, the waves, gathering strength from the whole length of the loch, break with great force upon this shore. At Dores Bay a similar but smaller and less stony beach may be seen.

A few aquatic plants are found in Foyers Bay, but only such as are common in the loch. The bay has been formed by detrital matter brought into the loch by the river Foyers. So great has been the amount of detritus brought down by this swift river that the bottom of the loch opposite its delta has been silted up to the extent of about 200 feet in vertical height. The works of the British Aluminium Company are situated at Foyers Bay. The selection of this remote spot as the site for an extensive mechanical industry is due to the water of the river Foyers affording a cheap motive power for the large turbines and dynamos that generate the enormous electrical force required for the operations of the Company. From Foyers to Borlum there is practically no shore flora, and where the bottom is agreeable to the development of submerged plants, only those species that are found elsewhere about the loch thrive. The submerged rocks are frequently covered with Algæ and Bryophyta, chiefly forms of Zygnema, Nardia, and Scapania (see Plates V. and VI.).

Loch Uanagan is situated in the Great Glen, about a mile south-west of Fort Augustus; it is about half a mile long, and is 43 feet deep in its deepest part. Its shores, which enter the water at a gentle slope, are sandy or stony, and its water is rather peaty. The affluent at the south-west end has introduced a large amount of detrital matter into the loch; a considerable area of shallow water thus formed is covered with vegetation. At the opposite end of the loch, although the water is shallow, there is little vegetation, owing to the erosive power of the waves caused by the prevailing westerly winds. The general features of the aquatic and marsh flora are similar to what is found in the shallow water and marshes of Loch Ness; there are, however, differences. Here we have a colony of Scirpus lacustris, the largest specimens of which rise 5 feet above the surface of water 7 feet deep. There is an abundant bottom carpet of Characeæ—Chara fragilis, var. delicatula, from the margin to 20 feet deep, and Nitella opaca from 10 to 30 feet deep. A considerable variety of other species occurs in this loch. From the north-west shore of the loch rises a considerable hill; this is covered with coniferous trees extending beyond the length of the loch and over the hill to the bank of the Caledonian Canal.

Passing along the Canal from Fort Augustus to Loch Oich, we encounter, in places where the Canal has been made through small and shallow lochs, a very abundant aquatic flora. The submerged sides of the Canal are also well clothed. All the plants, however, are those quite common to the waters of the district, and call for no special comment, except that Coiltry Loch is in parts simply filled with five dominant plants, namely, Lobelia Dortmanna, Isoetes lacustris, Littorella lacustris, Juncus fluitans, and Callitriche hamulata.

Loch Oich is the highest of the lakes in the Great Glen; it is four miles long, with shores and islands abundantly wooded. Set amongst lofty and rugged mountains, it presents a magnificent piece of highland scenery. The water is peaty, and, as a considerable area of the loch is so shallow that the bottom is within the photic zone, there is an abundant submerged flora, although restricted in variety, as at Loch Ness. The shores of this loch are stony or sandy, with a very sparse vegetation or none whatever. Notwithstanding the innumerable small bays and shallow shores, there is very little marsh, so that plants of this habit are not abundant. The Calder Burn has brought down a great amount of detrital matter into the loch, forming large gravel banks, but these are almost destitute of plants. The paucity of marsh and shallow-water vegetation in this loch must, I think, be due to the abundance of stones and sand and scarcity of mud. The hills hereabout are faced with glacial drift-gravel, which is brought into the loch by burns and deposited along the shores. This gravel is extremely antagonistic to littoral phanerogams, because it is continuously shifting under the power of the waves. These long, narrow lochs running in the direction of the prevailing winds always have barren shores, owing to the waves having power over practically the whole of the loch; this is more especially the case if the shores happen to be of gravel.

Loch Lochy is not properly in the Ness Area, as it drains into Loch Linnhe. Some dredging operations by the *Mermaid*, at depths of from 100 to 500 feet, furnished exactly similar results to those obtained at Loch Ness, namely, non-fetid mud, a limited quantity of vegetable detritus, no living plants of the higher types, and a restricted number of bacteria and animals of low organisation. Beyond this I have only examined the north-east end of the loch, which is practically the same in character and flora as Loch Oich; the water, however, is less peaty. The mountains here also are faced with glacial drift-gravel, through which the numerous watercourses have carved enormous gullies, bringing down the gravel into the loch. By this action, two burns upon opposite shores have brought into the loch at Kilfinnan almost enough material to divide the loch in twain.

Lochan Coire Glas, in Glen Garry Forest, is an extremely wild little loch about 1600 feet above sea-level. Mountains rise precipitously from its margin to over 3000 feet, closing it in on three sides like an amphitheatre. Gusts of wind descending the mountains strike the loch with terrific force, notwithstanding its apparently sheltered position. This loch is gradually being silted up with detritus washed in by burns, or rather waterfalls, that descend the mountains. A sandbank in the middle of the loch is covered with Heleocharis palustris. A limited number of other plants also occur here, but all those that grow on the shores are very much dwarfed.

Lochan Diota is a small pool at an elevation of about 1000 feet, situated to the north-west of Loch Lochy. It is shallow, and is overgrown with a number of plants common to this Area.

Loch Lundie is north of Glen Garry, at an elevation of 445 feet above sea-level. The shores are flat and peaty, sandy, or stony. The water is peaty, and there is an abundant flora. Marsh plants grow luxuriantly on its western shores, but the eastern shores are comparatively bare; the western side is also well wooded. A large island on the east is covered with dwarf birch and alder. Some of the shallow bays on the west are entirely filled with Phragmites communis, others with Scirpus lacustris. Isoetes lacustris is extremely abundant, and carpets the bottom from 2 to 20 feet deep; in the deeper water the specimens were frequently 18 inches long. A considerable variety of other plants occurs both in the water and upon the shores.

Lochan Doire Chada is a small peaty loch situated between Loch Lundie and Loch Oich. The west side is composed entirely of a deep and dangerous bog, sparsely covered with dwarf Phragmites communis, Carex rostrata, etc. The east side is stony and destitute of plants, whilst quantities of the dead stems of Phragmites had been washed high on the shore by winter storms. This loch affords an excellent example of the difference between an eastern and a western shore due to winds. A very restricted variety of plants grows at this loch.

On the west of Loch Ness, among the mountains, there are a great many lochs at an average elevation of about 1200 feet; some, however, are over 1600 feet above sea-level. These fall naturally into groups, because the different series are separated by deep glens. They may be arranged as follows:—Taking the glens as boundary lines, there are the lochs on the mountains south of Glen Moriston, those on the mountains between Glen Moriston and Glen Urquhart, Loch Meiklie in Glen Urquhart, and the lochs on the mountains north of it. The lochs of these groups very closely resemble one another, both in general physical features and in their floras; it does not, therefore, seem necessary to describe each loch separately, especially as most of them are of but little botanical interest, consequently they will be described in groups.

South of Glen Moriston.—All the lochs situated in this group have peaty water. Their western shores usually have a more or less extensive area of marsh, upon which flourish plants common to the Area. Their eastern shores are universally stony or rocky, and always almost or quite destitute of plants; whilst trees are entirely absent. The plants that flourish at one or another of these lochs are as follows:—Littorella lacustris, Lobelia Dortmanna, Isoetes lacustris, Fontinalis antipyretica, Chara fragilis, var. delicatula, Nitella opaca, Juncus fluitans, Callitriche hamulata, Potamogeton natans, P. polygonifolius, P. lucens, Myriophyllum alterniflorum, Utricularia intermedia, Sparganium minimum, Glyceria fluitans, Menyanthes trifoliata, Comarum palustre, Equisetum limosum, Heleocharis palustris, Carex rostrata, C. Goodenovii, C. aquatilis, C. binervis, C. dioica, Eriophorum vaginatum, E. polystachion, Triglochin palustre, Juncus effusus, J. articulatus, Caltha palustris, Ranunculus Flammula, Hydrocotyle vulgaris, Sphagnum acutifolium, S. cuspidatum, var. plumosum, Hypnum stramineum, H. trifarium, Rhacomitrium aciculare, Scapania undulata, Nardia compressa, Batrachospermum moniliforme, Zygnema Vaucherii, etc.

Crossing Glen Moriston, through which flows a splendid river, a desolate mountain region is entered, remarkable for the great number of its lochs. With the exception of dwarf birch or mountain ash on the islands of a few of them, their shores are treeless and frequently entirely devoid of vegetation, excepting on the western side. Their waters are without exception peaty, often extremely so. Occasionally Betula nana is found spreading over a rocky shore. This plant is very abundant on the moors of the district, and is often of considerable size, the largest specimens having stems as thick as one's wrist; they are, however, always prostrate. The lochs of this extensive region, containing about 100 square miles of mountain and moor, are characterised by a general paucity not only in variety, but frequently also in quantity, of phanerogamic plants. It often happens that the plants, particularly those of the littoral zone, are very much dwarfed. A small terrestrial form of Sparganium minimum grows at the margin of some of these lochs. Dwarf forms of Castalia speciosa and Menyanthes trifoliata, sometimes growing on exposed peaty mud, are frequently met with. The most abundant marsh plants are Carex rostrata, C. filiformis, C. Goodenovii, and Equisetum limosum. These sometimes cover very considerable areas of marshy ground, but, unless there is some exceptional condition present, such associations never occur on the eastern shores. At Loch a' Mheig, which is sheltered from westerly winds by hills, the marginal vegetation is encroaching upon the water in crescent formation on all sides of the loch. This is due to the wind-sheltered position, to the shallow and regular, basin-like inclination of the bottom, and to the detrital matter brought into the loch by a burn. In this particular case the conditions are exceptional for favouring marsh development on the eastern side; the plants concerned are chiefly Carex rostrata and

C. Goodenovii. On some of the higher hills of this district Arctostaphylos alpina is very abundant. The chief plants at this group of lochs are as follows:—Littorella lacustris, Lobelia Dortmanna, Isoetes lacustris, Fontinalis antipyretica, Nitella opaca, Chara fragilis, var. delicatula, Juncus fluitans, Myriophyllum alterniflorum, Callitriche hamulata, Utricularia vulgaris, U. intermedia, Potamogeton natans, P. polygonifolius, P. lucens, P. prælongus, Menyanthes trifoliata, Castalia speciosa, Sparganium natans, S. minimum, Caltha palustris, Heleocharis palustris, Equisetum limosum, Glyceria fluitans, Carex rostrata, C. filiformis, C. aquatilis, C. Goodenovii, C. binervis, Eriophorum vaginatum, E. polystachion, Juncus articulatus, J. supinus, Triglochin palustre, Ranunculus Flammula, Sphagnum various sp., Blindia acuta, Brachythecium rivulare, Hypnum cuspidatum, H. uncinatum, Philonotis fontana, Scapania undulata, Nardia emarginata, N. compressa, Batrachospermum moniliforme, Zygnema Vaucherii, etc.

Loch Meiklie is situated in Glen Urquhart, at an elevation of 365 feet above sea-level. It differs from the lochs of this area hitherto considered. Its shores are beautifully wooded, and mostly stony or sandy; but about the embouchure of the river Enrick at the west end there is a considerable swamp. Some of the sheltered bays, notably towards the north-east, have also swampy margins. Besides moorland, this loch also drains a small area of cultivation; its water is, therefore, less peaty than usual, although it contains a considerable amount of matter in suspension. At the marsh at the west end of the loch, the plants are arranged in succession somewhat as follows, proceeding from the drier ground towards the water:—Juncus effusus, J. articulatus, Carex rostrata, Phragmites communis, Equisetum limosum in water 2 to 5 feet deep, Castalia speciosa in water 4 to 8 feet deep, Nymphæa pumila in water 8 to 10 feet deep; beyond the last-mentioned, at the bottom, Potamogeton pusillus, var. tenuissimus, P. lucens, Utricularia vulgaris, and Nitella translucens. All these associations are of course mixed with other plants, but those mentioned are dominant over a certain area. The Castalia speciosa association is extremely well developed here, and presents a magnificent spectacle. A considerable number of other plants also occur at this loch.

Ascending the hills north of Glen Urquhart, there are many mountain lochs differing somewhat in character from any hitherto seen, although some are of the usual mountain type. Many of the lochs on these hills have a great abundance of Castalia speciosa in its normal form, the associations of which frequently extend in huge crescents, chiefly about the western side of the lochs or in bays. There is also in many cases a luxuriant swamp of Scirpus lacustris, etc. The general vegetation of the lochs, although restricted in species, is more exuberant than that usually seen in hill lochs, and in fact closely resembles that of wind-exposed lowland lochs. This is probably due to two causes:—1st, the lochs are sheltered from the prevailing wind by adjacent hills; 2nd, moorland peat is not abundant above the level of the lochs, so that their waters are less peaty than usual; besides which seams of limestone occur in these hills, and its influence is undoubtedly felt in the lakes. Otherwise than by the greater luxuriance of some of the species, and excluding the large associations of Castalia speciosa and Scirpus lacustris, the flora of this group of lochs resembles that of those just described.

Adjoining the beach of Loch Ness at Aldourie there is a small lake entirely surrounded and covered with vegetation. From Loch Ness shore, where not a single water plant can be observed, thirty paces bring one to this little loch, which is entirely overgrown with aquatic plants. Surely, but for the unsuitable shore of the former loch, some of these plants would occur in it also! Other similar lochs of small size occur hereabout, and another, but larger, is situated behind the great beach at the north-east end of Loch Ness. The vegetation at these sheltered lochs grows with much greater exuberance than the same species at the hill lochs. Besides a number of common plants, the following occur at one or another of these smaller lochs:—Montia fontana, Apium inundatum, Lysimachia vulgaris, L. nemorum, and a curious form of Juncus acutiflorus having flowers and nodes viviparous, the young plants from the nodes being quite large.

East of Loch Ness there is a series of lochs, many of considerable size, lying at elevations of from 600 feet to 1000 feet above sea-level.

Loch Ashie is 718 feet above sea-level, and is situated upon an open moor. It is about a mile and a half long, with flat and stony shores and rather peaty water. On the east side a bleak and dreary moor rises gradually from the loch; on the west the shores are clothed with coniferous forest. Towards the south-west the land has been recently deforested, so that this portion is as featureless as the eastern shore. This loch has a very poor flora, particularly upon its shores.

Loch Bunachton is an extremely desolate sheet of water, situated in the bottom of a vast treeless moor. It is smaller than the last-mentioned, but otherwise resembles it in character and flora.

Loch Culcairn is a recently constructed artificial lake, and the water, which is very peaty, presents little of botanical interest. Originally there existed on the site a small tarn and extensive peat-diggings. The dam is at the north end.

Lochan Dubh, at Dunlichty, is a small peaty pool entirely surrounded with coniferous forest. It is of no particular botanical interest.

Loch a' Chlachain is 684 feet above sea-level. The surrounding country is extremely wild and rocky. The water is clear, owing to the fact that the area of peat drained by it is comparatively small. This loch drains Loch Dùn na Seilcheig, which in turn drains Loch Cèo-Glas. The whole catchment area of these lochs consists largely of bare rock, covered in many places with enormous patches of Arctostaphylos Uva-Ursi. Heather and peat are often restricted to the interstices between the bare boulders; consequently the water of these lakes is unusually clear, but doubtless very poor in plant food-salts. The rock-bound shore of Loch a' Chlachain is not conducive to a littoral flora; plants are consequently scarce excepting at the west end, where the shore is flat owing to detrital matter deposited by the affluent. This part is covered with marsh vegetation, which, like that in the water, consists only of the common types found throughout this Area.

Loch Dùn na Seilcheig is one of the largest lochs in the Ness Area. It is a magnificent sheet of water 3½ miles long by one mile wide, and is 703 feet above sea-level. Nothing was seen here save such plants as are common throughout the Area.

Loch nan Gead'as is a small pool at the south-west end of Loch Dùn na Seilcheig, and is joined to it by a narrow channel which has wide, marshy flats on either side. This loch is more or less surrounded by a swamp, which bears an abundant vegetation. From the land towards the water there are zones of the following plants:—Myrica Gale, Comarum palustre, Carex rostrata, Equisetum limosum, and Castalia speciosa, besides which there are a number of other ordinary plants.

Loch Cèo-Glas is a long, narrow loch 763 feet above sea-level, and situated below Tom Bailgeann. The south-east shore has colonies of Carex rostrata and Phragmites communis in sheltered bays. The north-west shore is bare and stony. At the south-west end there is an extensive marsh, covered with Equisetum limosum, Carex rostrata, etc.

Lochan a' Choin is a small loch in a partially cultivated district. The water is peaty. The western shore is flat, consisting of muddy peat, and is overgrown with a considerable amount of vegetation, which presents the usual features of the district. The eastern shore is stony and bare of plants.

Lochan nan eun Ruadha is near the last-mentioned, but is much larger and is very bare of plants. The south-west side has deep water quite up to the thick peat bank, so that there is no shore whatever. The eastern and northern portions have a shore of stones and rocks, and a very sparse vegetation. The western side has a marshy area, which is chiefly occupied by groups of Phragmites communis.

Loch Ruthven is a fine sheet of water some two miles long and

700 feet above sea-level, with peaty water. The east and west ends are silted up with sand, so that there is a considerable area of shallow water at both ends, but more especially so at the east end. The shores are frequently sandy—more so than is general; they usually enter the water at a gentle inclination, and vegetation is abundant. The shallow areas at each end of the loch are often densely carpeted with the ordinary plants. The water is of a darker tint than that of Loch Ness; on that account the photic zone does not extend beyond a depth of 23 feet, which, however, includes the greater portion of the bottom, as the loch is shallow. At the time of my visit the water was much more turbid at the east than at the west end; this was probably due to the shallow area at the west end being of much less extent than at the east end. The greatest average depth and bulk of water being at the west end, the sediment at the bottom is below the influence of the waves. At the east end, however, a large area is within this influence, and the sediment is easily raised. Moreover, for some days previous to my visit there had been a continuation of stiff westerly winds. The flat, sandy shore at the east end is covered with moorland vegetation. Looking from the rear of the shore towards the water, the foreground is thickly clothed with Calluna vulgaris, Myrica Gale, Juncus squarrosus, Nardus stricta, Deschampsia flexuosa, Juncus effusus, etc. Nearer the water the plant-covering becomes thinner, then isolated clumps of plants stand up out of the sand, and finally even these disappear, so that close to the water nothing remains but bare sand. At the north-east end of the loch a large bay is filled with Equisetum limosum; its existence here is due to the shelter afforded by a wooded hill from the westerly winds, and it is interesting to notice how abruptly the association terminates where the protection afforded by the hill ends. At the west end of the loch there is a large sandy flat several acres in extent; this is almost entirely overgrown with Juncus effusus, the tussocks of which are closely compacted, near the water, but thin out considerably as the land becomes drier, and finally give way altogether to meadow-land. There are also large colonies of Carex rostrata and Phragmites communis. I have never found elsewhere such an abundance of Utricularia vulgaris as occurs at this loch at depths of from 5 to 10 feet. There was also a great abundance of that fine moss, Hypnum scorpioides, app. var. miquelonense, at similar depths. Besides those already mentioned, the following plants occur here, and this forms a representative list of the flora of other lochs in this district:—Littorella lacustris, Lobelia Dortmanna, Isoetes lacustris, Fontinalis antipyretica, Nitella opaca, Chara fragilis, var. delicatula, Myriophyllum alterniflorum, Juncus fluitans, Potamogeton pusillus, P. lucens, P. prælongus, P. polygonifolius, P. natans, Callitriche

hamulata, Polygonum amphibium, Sparganium natans, Glyceria fluitans, Carex rostrata, C. Goodenovii, C. aquatilis, C. flava, Heleocharis palustris, Eriophorum polystachion, Comarum palustre, Menyanthes trifoliata, Caltha palustris, Triglochin palustre, Pedicularis palustris, Cardamine pratensis, Ranunculus Flammula, Spiræa Ulmaria, Hydrocotyle vulgaris, Scapania undulata, Nardia emarginata, Conferva, Zygnema, Batrachospermum, etc.

An Dubh Lochan is a small loch near the last-mentioned. It is entirely surrounded by a wide swamp, owing to which the water is almost unapproachable. The plants are those usual to the district.

Loch a' Choire is situated a little to the north of Loch Ruthven, at an elevation of 865 feet above sea-level. The water is not very peaty. The south-east shore is flat, mostly sandy, and merges gradually into moorland. Otherwise the shores are rocky or stony, excepting for sandy bays here and there. Abruptly from its north-west shore there rises a considerable hill, the upper portion of which ends in a bold, perpendicular escarpment. The scanty vegetation consists of a few of the species common to the district.

Loch Dunmaglass is partially an artificial loch, the original one having been extended by the construction of a dam at the north-east end. Meall Nochd rises almost perpendicularly from its western shore, and the flank of Beinn Dubh-choire, on the east, is also steep. Being closed in by precipitous and bare rocky mountains, having but little peat, its water is clear and only slightly peaty. The scenery is very wild. It is remarkable for being the only loch in the Ness Area in which I found Hippuris vulgaris, but only the submerged shoots occurred. The other plants of the loch are of the species usual to the district.

Loch Mhor.—In this large loch I found not a trace of any living plant. It is over 600 feet above sea-level, and the water is extremely peaty. Originally there were two lochs on this site, Loch Farraline and Loch Garth. In order to secure a constant and efficient supply of water for their turbines, the British Aluminium Company at Foyers, who own the lochs, undertook operations by which the two lochs were joined. By this work the level of the lower loch was raised some 20 feet, by means of a dam, whereby one large loch was formed having a total length of about five miles; and this was named Loch Mhor. The Company's turbines utilise an enormous amount of water; consequently, in accordance with the rainfall, the surface level of the loch is continually changing, the difference between maximum and minimum being about 22 feet. Now, the water of this loch is so dark that, reasoning from other cases, I should imagine no plants could exist at a greater depth than 10 or 12 feet. The consequence, therefore, of an extra 20 feet of this dark water was to kill out the whole of the aquatic flora of the original lochs, and the ever-changing level has not favoured the introduction of a new flora; in fact, I doubt if an aquatic flora could exist there under the present conditions. Not only were all the aquatic plants of the original lochs destroyed, but the entire littoral flora was also extinguished by drowning, so that, when the water is low, the remains of the old littoral trees and shrubs, which have not yet decayed, form a desolate picture of death and destruction.

Between Loch Mhor and Loch Ness there are a few small lochs that are very similar to one another in both their physical features and their flora. Their water is usually peaty, and their shores on the east side are frequently more or less stony, whilst the western shores are generally marshy. Most of them have large associations of Castalia speciosa, which, with copiously wooded shores and a general luxuriance of vegetation, give them a decidedly lowland appearance. The plants, however, notwithstanding the general exuberance of growth, are such as are usual to the peaty lochs of this area. On the west side of Loch an Ordain there is an extensive marsh, which is overgrown with Carex rostrata as the dominant plant. In the middle of the marsh, however, there is a circular pool in which the water is too deep for the Carex, and one side of this is overgrown with Castalia speciosa. Such circular pools, forming a portion of a larger loch, are known under the unpleasant appellation of "murder-holes." In the seven Areas described in this paper I have only seen two other well-formed holes of this kind, namely, at Loch Kilcheran in Lismore, and Loch Neldricken in Kirkcudbrightshire.

Loch Kemp is beautifully situated amongst hills, some of the lower slopes being wooded with birch. The shores are mostly rocky, the water is very peaty, and the vegetation is extremely scanty. When looking over the side of a boat the bottom is quite invisible at a depth of 5 feet. On the north-east side the bottom, within the photic zone, is to a great extent incrusted with a hard, brittle layer, about half an inch thick, resembling moor-pan; no plants grow on this substance. In other places there is a bottom carpet of Littorella, Lobelia, and Isoetes to a depth of 12 feet; beyond this depth there are no plants. The other plants observed here are as follows:—Callitriche hamulata, Juncus fluitans, Utricularia vulgaris, Potamogeton natans, Castalia speciosa, Equisetum limosum, and Carex rostrata, but none of them were abundant. Any other littoral plants were merely isolated specimens of common species here and there among the rocks.

Loch Knockie is about one and a quarter miles long. It much resembles Loch Kemp in general features, but its water is less peaty, and vegetation is rather more plentiful. The photic zone extends to a depth of 25 feet, at which depth Nitella opaca grows. Carex rostrata, Equisetum limosum, and Phragmites communis abound in sheltered bays. No unusual features, nor any but ordinary plants, were observed. There are several islands in the loch; its shores are well wooded, and it presents a very pleasing piece of highland scenery.

Loch nan Lann possesses great natural beauty. It is smaller than its neighbour, Loch Knockie, which in general features it closely resembles. Its flora is composed of species usually found in the lochs of this Area.

Loch Tarff is 956 feet above sea-level; its shores are mostly stony and rocky, and its water is peaty. It lies in an open, wind-exposed position on the moor. It has several small islands, the largest of which is the breeding-place of a great number of gulls. This island is overgrown with stunted birch, alder, and willow, with an undergrowth of Calluna, etc. The branches of the trees are thickly invested with the lichen Alectoria jubata, which gives them a fantastic appearance. Another island has an undergrowth of Epilobium angustifolium and Capnoides claviculata; a third has an abundance of Cnicus heterophyllus; yet none of these plants appear to be abundant anywhere else near the loch. Ranunculus hederaceus occurs sparingly on the shore. A considerable number of other plants grow in and around this loch, but merely those of common occurrence.

Loch Killin is situated at an elevation of over 1000 feet above sea-level, in a narrow and deep glen overshadowed by mountains. Its shores are rocky, excepting at the south end, and its water is peaty. A lofty and precipitous escarpment enters the loch on its western side. The aquatic flora is that which is quite common to other peaty lochs. Mention must, however, be made of the large quantities of Glyceria fluitans and Sparganium natans that occur in the water, particularly at the south end. An interesting feature of this loch is the remarkable amount of detrital matter brought into it by the river Killin. The bottom of the glen south of the loch forms a flat strath, about two miles long, consisting of the alluvial sand and gravel brought down by the river. Towards the loch many acres of this strath are covered with Juncus effusus, having grass etc. between the tussocks. The south shore of the loch consists of this alluvium, and it forms a beach of gravel and sand of considerable extent; it is, in fact, simply an extension of the strath upon which vegetation has not yet grown. Standing at the margin of the loch and looking up the strath, we see extending out over the gravel, from the main body of the vegetation farther up, patches and isolated plants of Nardus stricta, Deschampsia flexuosa, Festuca ovina, Molinia cærulea, Scirpus cæspitosus, etc. In the rear of these plants, isolated tussocks of Juncus effusus occur as the vanguard from the large association farther up the strath; such sward as exists between these tussocks is mostly composed of dwarf and densely matted Equisetum arvense.

About six miles to the south-east of Fort Augustus, between the mountains of Carn a' Chuilinn and Cairn Vangie, is an extensive plateau some 2200 feet above sea-level, wild and desolate in the extreme, and known locally under the sobriquet of "Siberia." Upon this plateau there are about twenty lochs, which are probably the highest series of lochs in the British Islands. Their shores are mostly rocky and stony, their water is invariably peaty, and not only their shores but the whole plateau is entirely devoid of trees. The terrestrial vegetation of this district is of the moorland type, Calluna and grass-like plants dominating. Where littoral marsh occurs, it is always on the western side of the lochs or in sheltered bays. Carex rostrata grows most luxuriantly—in fact, the largest specimens I have seen of this species were at these lochs. Equisetum limosum also grows well in some of the lochs; but I have observed that when growing near the Carex rostrata associations they scarcely grow taller than the latter, whereas in the lowlands they grow twice as high, or even more. These two species usually grow near one another at the margins of the lochs, the Carex always being next the land. Now, as they only grow on the western sides of the lochs, the Carex is of course always to the windward of the Equisetum, which is thereby sheltered from the prevailing wind. I think that is the reason for the latter not overtopping the former, because the desiccating action of the wind at this elevation must be considerable, and its effect would be much greater upon the growing apex of the Equisetum than upon the leaves of the Carex. No boat being available, I could not obtain evidence regarding the bottom flora of these lochs, beyond what I could glean from their margins; but the following plants were found, some of them being dwarfed:—Littorella lacustris, Lobelia Dortmanna, Isoetes lacustris, Fontinalis antipyretica, Chara fragilis, vars., Juncus fluitans, Myriophyllum alterniflorum, Callitriche hamulata, Utricularia intermedia, Sparganium minimum, Potamogeton polygonifolius, P. natans, Equisetum limosum, Carex rostrata, C. Goodenovii, C. aquatilis, Eriophorum vaginatum, E. polystachion, Caltha palustris, and Ranunculus Flammula. Wet and submerged rocks were often covered with Scapania undulata, Nardia compressa, Blindia acuta, etc. Species of Sphagnum abound on boggy shores. In sheltered places Batrachospermum moniliforme, Zygnema Vaucherii, etc., are plentiful. Armeria maritima grows upon some of the littoral rocks. A few of the lochs have islands, and these are sometimes occupied by colonies of gulls, which breed there.

Area II

The island of Lismore is situated in the entrance to Loch Linnhe, off the coast of Argyllshire; it is 10 miles long by 1½ miles broad at the widest part. Here the conditions are absolutely different from those existing in the Ness Area. There is no moorland peat formation at Lismore that can possibly drain into the lakes. The geological formation throughout the island is limestone. In reply to a question regarding this limestone, the Geological Survey write:— "The Lismore limestone belongs to the metamorphic rocks of the Highlands, and is probably the equivalent of the Blair Athole limestone." The land is almost entirely in a more or less cultivated state; a fine, bright green grass sward covers a large portion of the island. The bright green appearance of the grass-land is worthy of mention; it at once arrests the eye, as being something different from what usually occurs in the Highlands. Large numbers of cattle and sheep are maintained upon the island, so that instead of humic acids an appreciable supply of ammonia salts will be likely to gain access to the lakes. The climate is mild, as the number of luxuriant Fuchsia shrubs in the gardens of the cottagers testifies. The three lochs on Lismore are but slightly elevated above sea-level, and are sheltered from wind by adjacent low hills. A marked difference between these and the lochs of the Ness Area is, that the waters of these lochs are heavily charged with calcium carbonate. Calcium carbonate is not itself directly a plant-food, but with many plants the presence of calcium salts will lead to the increase of their absorption of ammonium and potassium salts. By other plants the presence of calcium in large quantities cannot be tolerated. It is not at present possible to give a comparative analysis of the water of several of the lakes under investigation. It may, however, be interesting to give an analysis of the water of Loch Baile a' Ghobhainn at Lismore, by Dr W. E. Tetlow, along with one of the water of the Lake of Geneva, as published by Forel.

One litre (or one million parts) contains (parts or) milligrams:—

	Lake of Geneva.	Loch Baile a' Ghobhainn.
Sodium and potassium chlorides	1·8	3·725
Sodium sulphate	15·0	...
Sulphuric acid	...	trace
Ammonium sulphate	trace	...
Ammonia	...	trace
Calcium sulphate	47·9	...
Basic calcium phosphate	...	0·094
Calcium nitrate	1·0	...
Nitric acid	..	trace
Calcium carbonate	73·9	151·161
Silica	3·7	2·635
Lithium	...	trace
Alumina and ferric oxide	1·9	...
Iron carbonate	...	1·158
Magnesium carbonate	...	1·414
Organic matter and loss	11·9	30·913
Total solids	157 parts in one million	191 parts in one million

In contradistinction to the lakes of the Ness Area, the water of the Lismore lakes is pellucid. It is so clear that one may look over the side of a boat and see the bottom through 25 feet of water. In consequence of their clearness, the photic zone for the more highly organised plants is less restricted than in the Ness Area. The shores also present quite a different aspect from those of the peaty lochs. Here the rocks and stones are covered with an incrustation of lime, which gives them a peculiar sponge-like appearance. The rounded, water-worn, and polished stones found on the shores of Loch Ness are not to be seen at Lismore. As the lakes are sheltered from the wind by low hills, their shores are not subjected to frequent and powerful erosion by the waves; they are consequently more or less surrounded with a littoral vegetation. Many of the plants in these lochs are heavily coated with an incrustation of carbonate of lime, a phenomenon unknown in the Ness Area. Myriophyllum spicatum, for example, is so burdened in this way that the plants are mostly unable to rise to the surface for the purpose of pollination; as the plants remain submerged, fertile specimens of this species are consequently not common in these lochs. Calcium carbonate ($CaCO_3$) is but slightly soluble in pure water; the presence of carbonic acid, however, enables the water to take up considerable quantities in the form of bicarbonate [$Ca(HCO_3)_2$], and hard water results from its occurrence in this soluble state. As the result of assimilation by plants inhabiting hard water, the carbonic acid is absorbed and the insoluble calcium carbonate precipitated. It is this precipitate that forms the incrustation on the plants. The lime incrustation on the stones of the shore is formed by minute lithophilous Algæ, in the process of their metabolism, in a similar manner to that by which the same substance is deposited on the stems of aquatic phanerogams. I have only seen similar lime-incrusted stones at one other place in Scotland, namely, Rescobie Loch in Forfarshire, but the phenomenon probably occurs wherever lime is abundant.

The lime-incrusted Characeæ are extremely abundant in the lochs of Lismore, and carpet the bottom with dense masses of their brittle shoots, from the margin down to 40 feet deep. When a boat is brought near the shore, one can hear the Chara grating upon her bottom with a rasping noise. Besides the showers of lime flakes that are continually falling from living aquatic vegetation, after the death of the plants any remaining lime incrustation will be broken up and it, too, deposited upon the bottom of the loch. In this way a lacustrine deposit of lime is being laid down at the bottom of these lakes, mixed with diatoms and other organic remains. The analysis of the water proves it to be rich in plant food-salts, and this is borne out by the exuberance of the vegetation.

From the foregoing statements it will be inferred that the flora of the lakes at Lismore differs considerably from that of the lakes in the Ness Area. Three illustrations are given in the original paper.

Loch Fiart is situated in the south portion of the island, and is about two-thirds of a mile long. It has a reedy margin composed of Phragmites communis and Scirpus lacustris.

Loch Kilcheran is nearly two miles north of Loch Fiart, and, like it, has a reedy margin of the same plants, which at the north end cover an extensive area. A circular pool is shut off from the main body of the loch by these plants, at the north end, forming thereby a "murder-hole."

Loch Baile a' Ghobhainn is situated in the north portion of the island. It is about two-thirds of a mile long, and agrees with the other lakes in having a similar reedy margin. The south end is occupied by an extensive tract of Scirpus lacustris, and at the north end, in the rear of a zone of the same plants, there is an extensive bed of Phragmites communis, which had been cut for economic purposes.

Not only in the reedy margin, in the water, in the shores, and in the general aspect do these three lochs agree with one another, but also in their general flora, so that the following list of species may stand for any one of them:—Littorella lacustris, Chara aspera, var. desmacantha, 2 to 20 feet deep; C. fragilis, var. delicatula, 10 to 20 feet deep; C. hispida, var. rudis, 25 to 35 feet deep. All these species of Chara are heavily incrusted with lime. Fontinalis antipyretica, to a depth of 40 feet; Hypnum scorpioides, a very robust form, 3 to 5 feet deep; Utricularia vulgaris, to 12 feet deep; Myriophyllum spicatum, to 10 feet deep (*vide ante*); Potamogeton perfoliatus, 10 to 24 feet deep; P. natans, to 20 feet deep; P. pusillus and its var. tenuissimus, 2 to 12 feet deep; P. lucens, P. filiformis, Nymphæa lutea, and Castalia speciosa. Hippuris vulgaris is very luxuriant and abundant to a depth of 10 feet, with the flowering stems above the surface even from that depth. Looking over the side of a boat, the subaqueous meadow of foliage formed by the barren shoots of this elegant plant was a sight not easily forgotten. Scirpus lacustris, Equisetum limosum, Phragmites communis, Glyceria fluitans, Menyanthes trifoliata, Polygonum amphibium, Heleocharis palustris, Comarum palustre, Sparganium ramosum, Carex rostrata, C. Goodenovii, C. aquatilis, C. flacca, Samolus Valerandi, Alisma Plantago, Radicula officinalis, Myosotis palustris, Iris Pseud-acorus, Eriophorum polystachion, Cardamine pratensis, Stellaria uliginosa, Pedicularis palustris, Triglochin palustre, Juncus effusus, J. articulatus, Caltha palustris, Veronica Anagallis, Senecio aquaticus, Montia fontana, Parnassia palustris, Hydrocotyle vulgaris, Ranunculus Flammula, Lythrum Salicaria, Epilobium palustre, Spiræa Ulmaria, Eupatorium cannabinum, Cladophora fracta floating in the water and about aquatic plants, and Zygnema Vaucherii on smooth rocks, etc.

A comparison with the lists of plants growing in the peaty lochs of the Ness Area will show that some of the most dominant plants there, *e.g.* Lobelia Dortmanna, Isoetes lacustris, Callitriche hamulata, Juncus fluitans, etc., are absent at Lismore; whilst certain species flourish in the lochs of the island that do not occur in the Ness Area.

Area III

The Lakes near Nairn differ in many respects from those of the two Areas already described. The lochs in the foregoing Areas mostly owe their existence to the action of glaciers, and are frequently situated in deep valleys overshadowed by hills, or in excavations upon the mountains themselves, rock and precipice being a characteristic feature of their rugged and frequently treeless shores, while considerable and often great depth is a marked feature. Here, however, there are extensive sheets of water existing in mere depressions among former sandhills of the sea-shore. Their shores are flat, muddy, and, but for the artificial forest about them, featureless. Where vegetation is abundant the mud is deep and evil-smelling when disturbed. In the two former Areas described a continuous flat and muddy shore has not occurred, neither has the mud often been of the stinking kind. True, in many of those lochs the windward shore presents a considerable stretch of bog, reclaimed from the loch by the accumulations formed by many generations of plants or by the detrital matter from a stream. It is, however, nearly always a more or less liquid peaty matter, not often evil-smelling when disturbed. This stinking mud, such as is commonly found in non-peaty lakes, *e.g.* Duddingston Loch near Edinburgh, results from the rapid decomposition of animal and vegetable remains. The decomposition of organic matter in these non-peaty waters takes place with far greater rapidity than in water charged with humic acids. In the first stages of decay the albuminoids are peptonised; then the carbohydrates become disorganised and pass in gaseous condition into the surrounding water. With the advance of putrefaction comes the formation, among other substances, of ammonia, carbon dioxide, and hydrogen sulphide. It is the last-mentioned that gives the mud of non-peaty lakes such an offensive odour when disturbed. In the presence of humic acids this rapid putrefaction does not occur. Instead, the albuminous bodies become humified, and disintegration takes place slowly by a kind of carbonising process. At the bottom of Loch Ness, for example, vegetable remains, such as leaves, twigs, etc., first become brown, then black and brittle, gradually crumbling to powder, apparently without the generation of obnoxious gas. Large woody stems become very hard and black. Putrefaction in this case appears not to take place, but rather a kind of desiccation—if one may apply this term to a subaqueous process. Likewise the mud from the bottom of Loch Ness has not the slightest offensive odour, neither does it stain one's hands as the fetid kind does. Another cause for the difference existing between the lakes of the two areas under consideration is, that in the deeper waters of the Ness Area there is a large portion of the bottom of the lochs quite destitute of aquatic vegetation. The scattered organic detritus is therefore comparatively much less there than in the shallow lakes at Nairn, which have an abundant vegetation all over their bottoms. The refuse-eating fauna and bacteria existing at the bottom are consequently in the former case able to maintain an equilibrium between supply and demand, and the lake bottom consists essentially of the non-fetid excrement of these creatures. In lakes whose floor is wholly carpeted with vegetation, the supply of organic detritus is greatly in excess of the demand of any refuse-eating fauna that may exist, and therefore fetid mud results from the processes of unhindered decomposition. In these lakes there is little evidence of lime, and little or no acid peat extract. The water is somewhat stagnant, and, from the considerable amount of decomposing organic matter, it presents a turbid and unwholesome appearance. In these respects this district again differs from the two former Areas considered. In consequence of the depressed situation, and with surrounding forest, these lakes are much sheltered from wind. Although in close proximity to the sea, the water is not brackish.

The littoral vegetation is in general more luxuriant here than in the peaty lochs; it also occurs all around the lochs more or less, and not particularly at the west side, as in the lochs of Area I. Five illustrations are given in the original paper.

Loch Cran is about one-third of a mile long, and conforms with the description already given. It is very shallow, and has a bottom carpet of Chara aspera and Potamogeton heterophyllus over the greater portion of it, besides a considerable number of other plants both on the bottom and at the margin.

Loch Loy is somewhat larger than the last-mentioned, being about a mile long; a considerable portion of it, however, is very narrow. No boat being available at the time of my visit, I could not examine its bottom flora beyond the margins. In this respect it probably resembles Loch Cran, but it is said to be deeper. Typha latifolia grows abundantly on some parts of its shore. In some places the shore is flat, and consists of sandy mud without vegetation. This loch is more closed in by trees than the last-mentioned, and at one part of the narrow western portion, Carex rostrata grows completely across it. The following plants occur at these lochs:—Littorella lacustris, Lobelia Dortmanna, Chara aspera, Myriophyllum alterniflorum, Utricularia vulgaris, Potamogeton heterophyllus, P. natans, Hippuris vulgaris, Callitriche stagnalis, Scirpus lacustris, Equisetum limosum, Typha latifolia, Phragmites communis, Sparganium ramosum, Heleocharis palustris, Carex rostrata, C. flacca, var. stictocarpa, C. flava, var. argillacea, Menyanthes trifoliata, Comarum palustre, Iris Pseud-acorus, Radicula officinalis, Myosotis palustris, Alisma ranunculoides, Juncus articulatus, J. effusus, J. conglomeratus, Caltha palustris, Cardamine pratensis, Stellaria uliginosa, Pedicularis palustris, Mentha arvensis, M. sativa, Ranunculus Flammula, Hydrocotyle vulgaris, Spiræa Ulmaria, Enteromorpha intestinalis, Spirogyra crassa, Œdogonium capillare, etc.

The Culbin Sandhills adjoin these lochs. The progress of the sand over the land has been arrested by planting a zone of Pinus sylvestris, and by the same means land already taken possession of by the sand has been reclaimed. These sandhills are to be classed amongst the largest in Britain, and many interesting features in plant œcology may be seen there.

Area IV

Kirkcudbrightshire may be advantageously divided into two Areas by a line passing from Gatehouse of Fleet across the county in a north-easterly direction towards Thornhill in Dumfries-shire. All the lochs in Kirkcudbrightshire north-west of this line, including those on the border of Ayrshire in the neighbourhood of Loch Doon, are mostly of the nature of highland lochs. This district is characterised by mountain and moor; indeed, some of the highest mountains of Scotland, south of Perthshire, are found here. The lonely grandeur of its wild scenery, notwithstanding the paucity of purple heather, gives it rank amongst the foremost of Scotland's charms. Owing to the lack of good roads, the absence of footpaths, and the exceedingly rough and often impassable nature of the ground, the tourist seldom penetrates to the remote fastnesses where lies the wildest of the fascinating scenery. The mountains, for the greater part rounded and reduced by intense glaciation, are, where the rock is not altogether bare of soil, covered with grass-like associations of plants, which afford pasturage to enormous numbers of sheep. The predominance of grass-like associations over the mountains and moors, instead of heather, has a great influence upon the flora of the lakes, and will be described in due course. Not only that, but the pastoral life induced thereby stamps the inhabitants with characteristics different from those of the people living in localities that are chiefly devoted to sport, and engenders a higher type of ethics and a superior social organisation amongst the rural folk.

We may begin the examination of the lochs of this large Area at Loch Doon, proceed to those on the hills to the west and south-west of Loch Doon; thence by way of Lochs Trool, Dee, Grennoch, Whinyeon, Ken, Lochinvar, etc., to Loch Dungeon, and finish our tour on the eastern slopes of the Rhinns of Kells. The original paper contains forty-five illustrations of the lochs, etc. of this Area.

Loch Doon is the largest sheet of fresh water in Scotland south of Loch Lomond; it is 5½ miles long by 1½ miles wide in its widest part. Its surface is 673 feet above sea-level. Its depth, in the deepest part, is 100 feet, but generally it is not over 50 feet deep. Its water is rather peaty, and its surroundings are almost treeless. The shores are exceedingly rocky or stony, save for a sandy bay now and again. Everywhere it is surrounded by mountains and moors, which are covered, for the greater part, by grass-like associations of plants. The population of the district is extremely scanty; the only houses are those of shepherds or small farmers, and the total number of these will scarcely exceed a dozen throughout its whole drainage area. The scenery, as may be gathered from the foregoing remarks, is wild and lonely; yet the broad outlines of the loch, flanked by mountains picturesquely silhouetted, give it a grandeur peculiarly its own.

The shores of this loch are, for the major part, entirely bare of aquatic vegetation. Indeed, the erosive power of the waves on the rocky margins allows no opportunity for the development of aquatic plants; and even in the sandy bays that occur here and there, the same power, acting on the shifting sand, prevents any considerable growth of littoral vegetation. Occasionally in pools, situated on large rocks or in sheltered creeks, a few specimens of Carex Goodenovii or Phalaris arundinacea may be seen. A few similar species, with scattered specimens of Juncus articulatus and J. supinus, occur on wet, sandy places; and between the rocks, here and there, patches of Sphagnum cymbifolium or Fontinalis antipyretica may be observed, but always in small quantity. Nor do the littoral rocks bear any wealth of Bryophytes, although a few of the commoner sub-alpine and lowland species may be found. On the whole, it may broadly be stated that Loch Doon is destitute of either an aquatic or semi-aquatic marginal flora.

At a few feet above the normal water-level quantities of lichens clothe the rocks, and give the littoral a distinctive character. The most abundant of these lichens are Lecidea geographica, Parmelia omphalodes, and Sphærophoron coralloides. The first-mentioned is so plentiful, and so completely does it overgrow the rocks, that many parts of the shore are for considerable distances coloured bright yellow, and the zone to which its abundance is restricted presents a remarkable appearance. This zone is in reality at the ancient water-level of the loch previous to a reduction of its level by about 7 feet some 150 years ago. This lowering of the level was brought about by the construction of two tunnels for the effluent, instead of the natural outflow, for the double purpose of reclaiming land at the margin and admitting salmon to the loch. Why the Lecidea should be so abundant at the old water-level I am unable to explain.

I dredged this loch in a great many places from end to end, but beyond an average depth of about 7 feet I could obtain no evidence of the existence of any living plants at the bottom. Yet in suitable places the bottom from 2 to 7 feet deep often bears an abundant vegetation, which occasionally may be continued into shallower water; instance Littorella lacustris in a few little sheltered sandy creeks. The extinction of the submersed bottom flora at so shallow a depth as 7 feet is distinctly remarkable, because it is not brought about, as in some cases (p. 208), by the discoloration of the water. Here the bottom can be seen at a depth of 7 feet, when looking over the side of a boat, without the use of any apparatus beyond shading the eyes with one's hat in order to shut out the light reflected from the surface of the water. Reasoning, therefore, from similar cases of translucency, some vegetation should extend to a depth of 28 feet or more (p. 163). It has already been indicated (p. 217) that the grass-like associations of plants which cover the moors and mountains have an influence upon the flora of the lochs in this Area. At the first consideration one would imagine that the influence exercised upon the bottom flora of a loch by the substitution of grass-like plants over the moors for associations of Ericaceæ would be that of less peat extract getting into the water. Such, however, is scarcely the case, because the moors have an abundance of ancient peat below the grass, formed there previous to the development of the sheep-rearing industry. The influence is caused in a way one would little expect. In winter the dead leaves of the grass-like plants covering the moors, chiefly Molinia cærulea, which grows very luxuriantly here, but also Nardus stricta, Scirpus cæspitosus, etc., are blown or washed into the burns and drains, and are thence carried into the lochs. There, owing to the antiseptic action of the peaty water, these remains do not readily decay, but accumulate from year to year, and become spread out over the loch bottom in enormous quantity, and, of course, this stratum of dead grass prevents the growth of a bottom flora wherever it lies. The depth to which its influence extends varies somewhat in different lochs, and even in any one particular loch. In Loch Doon, at the south end, where the loch receives its principal supply of this grass from the rivers Gala Lane and Carrick Lane, it spreads over the bottom to within 5 feet of the surface of the water, and at other parts of the loch to about 7 feet below the surface. From these depths it is spread over the whole loch bottom more or less. Even at a depth of 50 feet the dredge came up choked with this deposit, which was almost black, but not of a particularly evil odour. The deposit in the loch must be the accumulation of many years, through the process of decomposition being so slow in the peaty water. At Loch Stroan (p. 227) a large amount of such dead grass is washed upon the east shore by the winter floods. Loch Stroan is a small, shallow loch, and in flood-time there is a very considerable current passing through it from the river Dee, so that a portion of the grass must be carried down the river into Loch Ken, besides that which is deposited high upon its own shore. Yet, notwithstanding these losses, Loch Stroan has an abundant supply of this material on its bottom. In the neighbourhood of Loch Trool there is much less grass available, and the bottom flora of that loch extends to a depth of 16 feet (p. 225).

The plants that flourish in Loch Doon are those common to highland peaty lochs. There was a curious submersed form of Peplis Portula growing to a depth of 3 feet, and Eurhynchium rusciforme at a depth of 3 to 5 feet, both flourishing at the south end of the loch. (For plants of Area IV. consult pp. 168–192.)

On the south-west of Loch Doon there is a large and somewhat circular elevated, treeless moor, three or four miles in diameter, surrounded by mountains on every side, and presenting the aspect of some huge amphitheatre in utter ruin. Rugged rock and deep bog vie with one another for possession of the space. Here a gurgling burn divides the combatants. There a broad lane[1] dashes over its rocky bed with foaming impetuosity; whilst ever and anon a slow, deep, sinuous river winds its labyrinthine course through some level stretch of moss, scarcely more stable than the river itself. Numerous lochs, characterised by stretches of coarse white sand intercalated here and there on the otherwise rocky or peaty shores, are sprinkled over this lonely and wild moor. Here flourish in great abundance two interesting forms of plants that I have met with nowhere else in Scotland, namely, *Ranunculus natans* and *Potamogeton pseudo-fluitans*, the former being a variety of R. Flammula and the latter a variety of P. polygonifolius.

Loch Recar is one of the largest of the lochs on the above-mentioned moor. It is about a mile across in either direction, and has a very irregular outline. The water is somewhat peaty, but, considering the moorland situation, remarkably clear and bright. The shores are rocky or peaty, but, on the east side particularly, large bays are filled

[1] A stream is often termed a lane in this part of Scotland.

with coarse white sand which is the result of the disintegration of the syenitic granite in which the loch is set. This sand is found chiefly on the eastern shores, in consequence of the erosive power of the waves caused by the prevailing westerly winds. The somewhat scanty vegetation is much more abundant on the western than on the eastern shores, saving that aquatic plants are much more plentiful in the long and narrow neck of water leading to the effluent on the east side than elsewhere in the loch.

Loch Macaterick is about a mile south of the last-mentioned loch, and is about the same size; the outline also is very irregular. This loch is almost cut in twain by two promontories which jut out from opposite sides of the shore near the middle. Like Loch Recar, it has a long, narrow effluent on the east side. There are also several small islands. The hill Macaterick rises boldly from the south shore; similarly but less boldly Maccallum rises from the south of Loch Recar. In the shores, water, and vegetation this loch also resembles Loch Recar.

Loch Slochy is half a mile south-west of Loch Recar. It is of some considerable area, but very shallow, and consequently almost entirely overgrown with associations of marsh plants, which spread over the adjoining boggy moor, so that in many places one has difficulty in discovering where the water ends and where the shore begins. This loch is well on the way towards the formation of another of those deep bogs with which the district already abounds. Phragmites communis and Equisetum limosum are the most abundant plants.

Loch Ballochling is a small sheet of water having the same general features as Loch Recar. It illustrates well the difference between east and west shores caused by the prevailing westerly winds; the west side has an abundance of plants, whilst the east side consists chiefly of sandy bays almost without vegetation. The most abundant plants at this loch are:—Carex rostrata, C. filiformis, Potamogeton polygonifolius, and *Ranunculus natans.*

Loch Goosie is about a mile west of the last-mentioned loch, and is similar to it in general features. Its dominant plants are Phragmites communis and Potamogeton polygonifolius; the beautiful moss, Pterogonium gracile, was abundant on the dry rocks of the shore.

Loch Brecbowie is about a mile north-west of the last-mentioned, and is at a greater elevation than any of the foregoing lochs. It is prettily situated amongst hills, in a pass leading from Loch Goosie to Loch Bradan. Waterhead Hill rises immediately from its east side. The margin is sinuous, and the very narrow zone of shore between the water and the moor is rocky, stony, or sandy; its general features are otherwise similar to those of the preceding lochs. Carex rostrata, Equisetum limosum, Phragmites communis, Lobelia Dortmanna, and Littorella lacustris are its most abundant plants.

Descending northwards from Loch Brecbowie for about a mile, one comes to Lochs Bradan and Lure, which are connected together by a narrow channel. Except for a plantation of conifers about the ruins of Craiglure Lodge, these lochs are entirely surrounded by a treeless, grassy moor. Their shores are rocky or stony, and the water is slightly peaty. On an island in Loch Bradan are the ruins of a small castle, but there is now little more to be seen than what is presented by a stone sheep enclosure. The vegetation here is very scanty, and of the same type as that which occurs in the lochs previously mentioned.

Passing over the hill by way of the little pool—Loch Dhu, which contains nothing of particular interest,—one crosses the Girvan Water and enters the desolate moor in which are situated Derclach Loch and Loch Finlas, connected by a narrow channel, and together forming the source of the water supply for Ayr. These lochs present nothing of botanical interest beyond a number of the plants common to the preceding lochs. They have a small extent of shore, which is mostly either rocky or peaty. The water is clear but slightly peaty, and the vegetation is scanty.

Proceeding from the head of Loch Doon towards Loch Enoch, by way of the glen drained by the Gala Lane, between the two mountain ranges, of which Merrick on the west and Corserine on the east are the highest points, one passes over the site from which Loch Doon obtains its chief supply of Molinia cærulea. Here is a stupendous bog five miles long by a mile or so wide, almost everywhere treacherous to walk upon, and in some places quite impassable. A characteristic feature of this bog is the luxuriant growth of Molinia cærulea, which is often about 18 inches high. The same grass also dominates the hillsides, but there it is much shorter.

After receiving numerous tributary streams the Gala Lane, for the last three miles of its course, is of some considerable size, and only in a few places can it be crossed, dry-shod, by jumping with alacrity from rock to rock across its bed. Sometimes it passes swiftly down a rocky incline; generally, however, it meanders its tortuous course, slow, deep, and wide. In such places flourishes a vegetation abundant in quantity but poor in variety, or its bottom may be covered with dead grass like that of Loch Doon, in which case no living vegetation occurs. Carex rostrata forms a marginal zone of varying width, and in the water Potamogeton natans, P. polygonifolius, Castalia speciosa, and Juncus fluitans are the dominant species. The last is so abundant that it appears to fill the river in places—yet in Loch Doon it is scarce.

Loch Enoch is 1617 feet above sea-level, and is the most elevated of a series of unique alpine lochs situated in a singularly rugged mountain region. It occupies a very wind-exposed position, which probably accounts for the sand of its shores being finer than that of other lochs in the district. Its outline is very irregular, and there are several small islands, the largest of which has upon it a small pool; hence the name Loch-in-loch, of which its better-known name, Loch Enoch, is said to be a contraction. There are several bays that have a shore of beautiful white sand produced from the disintegrated syenitic granite, of which these mountains are largely composed.

The shores of Loch Enoch, with the exception of the sandy bays, are rocky, and the water is exceptionally clear and sparkling, although slightly peaty. The flora is very poor in species. On the west side Sparganium natans is abundant in bays, and there are several small associations of Carex rostrata in bays on the west and north sides. Isoetes lacustris, Lobelia Dortmanna, and Littorella lacustris carpet the bottom in places. Juncus fluitans is very abundant, whilst Myriophyllum alterniflorum is scarce; Batrachospermum vagum, Zygogonium ericetorum, and Nardia compressa are abundant on the submerged rocks. Besides those mentioned, phanerogams are scarce, but the littoral rocks are clothed with a variety of Bryophytes.

Loch Neldricken.—Proceeding a few hundreds of yards to the south-east of Loch Enoch, one comes to a narrow ridge of rugged rock connecting Dungeon Hill with Craignaw. From this spot, called the Nick of the Dungeon, an excellent bird's-eye view is obtained of Lochs Neldricken and Valley. These lochs are similar in general features to Loch Enoch—clear, brilliant, slightly peaty water, white sandy bays, otherwise rocky shores and with very irregular outlines. The vegetation is also similar and usually scanty. On the north-west side of Loch Neldricken there is a very regularly shaped "murder-hole" formed in a somewhat circular bay or arm of the loch, the shallow margin of which affords a suitable situation for sedge-like plants. The bottom I presume sinks suddenly and regularly, like a basin, at some distance from the shore to a greater depth than these plants can accommodate themselves to; consequently they end abruptly and present an even circular outline at the place where the water is too deep for further advance. The plants surrounding this "murder-hole" are in three well-marked zones, as follows:—Adjoining the shore Carex rostrata, then a zone of Equisetum limosum, followed by a narrow zone of a plant which, from distant examination with a telescope, was apparently a large form of Carex rostrata, but as specimens could not be obtained it was impossible to exactly identify the species. In many places the sandy shores are covered with great patches of Nardia scalaris and Anthelia julacea, and the littoral rocks also are frequently overgrown with Bryophytes common to the district.

Loch Valley, as already indicated, is adjacent to the last-mentioned and receives its outfall. The physical and botanical features are similar to those of the adjacent lochs already described, but it has in addition Carex filiformis and Menyanthes trifoliata.

Loch Narroch is quite a small circular sheet of water at the east end of Loch Valley, which in physical and botanical features it resembles. The marginal submerged rocks were covered with remarkable quantities of Algæ, chiefly of the genera Batrachospermum, Ulothrix, Zygogonium, Zygnema, and Mougeotia.

Round Loch and Long Loch of Glenhead are both to the south of Loch Valley; they are, however, at a lower elevation and smaller. They much resemble the foregoing lochs, and, so far as I could glean, are of little botanical interest.

Loch Dee, which is $1\frac{1}{4}$ miles long and $\frac{3}{4}$ mile wide, is the largest of this series of lochs. It is situated at an elevation of 739 feet above the sea, amidst wild and lonely scenery, about five miles south of Loch Enoch. Although at a lower elevation, it is similar in general features to that and the neighbouring lochs, excepting that the sand of its shores is not white, but of a brownish tinge; the water also differs in being somewhat more peaty. The flora is extremely poor and presents nothing uncommon to the district. Bryophytes abound on the shores and on the exposed rocks. Very conspicuous also are the lichens which cover numerous rocks by the shore; the most plentiful of these are:—Platysma glaucum, Cetraria muricata, Parmelia lanata, P. omphalodes, Alectoria jubata, Sphærophoron coralloides, and Lecanora tartarea.

Dry Loch, Round Loch, and Long Loch of the Dungeon.—These are small sheets of water, each a few hundreds of yards long, and they are all connected by a stream which first flows out of the Dry Loch, that being the highest of the three; this stream ultimately becomes the river Dee. Their shores are stony or peaty, and the water is slightly peaty but clear. These lochs are situated at the highest and wildest part of the glen, between Dungeon Hill and Craignaw, and the scenery around is extremely fine. They have no feature of botanical interest beyond a number of such plants as are contained in the other lochs of the immediate neighbourhood.

Loch Trool is 246 feet above sea-level, and is $1\frac{1}{2}$ miles long by $\frac{1}{4}$ mile wide. It is approached from Loch Dee through a narrow, rugged, and trackless pass about three miles long. This loch affords a splendid piece of highland scenery, which is probably unequalled south of Perthshire. Mountains rise from the shores almost throughout its whole length, their lower slopes being clothed with either coniferous or deciduous-leaved trees. This loch much resembles

Loch Oich, but is smaller. The water is clear but slightly peaty. At the west end the margin is formed chiefly by peaty banks; elsewhere, except at the east end, which is flat and boggy, the shores are stony, rocky, or sandy, or the steep hillside enters the water directly without the intervention of a shore. The upper portions of the adjacent hills above the tree zone are mostly clothed with bracken and grass formations. The rank growth of the latter is here, however, much restricted, so that in comparison with Loch Doon there is but a small quantity of dead vegetation available for covering the loch bottom. Having noticed the relative scarcity of rank Molinia about the neighbourhood of this loch, I was anxious to discover to what depth aquatic plants flourished at its bottom. Careful dredging revealed the fact that the living vegetation here extends to a depth of 16 feet; at greater depths the dead remains of Molinia, Carex, etc., cover the bottom, and no plants flourish within this zone. The flora of the loch is poor in the number of species, but some of the plants occur in great abundance. About the west end, at which is the effluent, the loch is narrow, shallow, and bears a considerable vegetation. Beds of Carex rostrata are abundant, and on drier parts of the boggy shore these are gradually or suddenly exchanged for other marsh plants. At the east end the affluent passes through an extensive delta, which is overgrown with marsh plants common to the district. The shore rocks, which are not a particular feature of this loch, bear a number of common Bryophytes, etc.

Loch Grennoch, by Cairnsmore of Fleet, is a fine sheet of water 2 miles long by $\frac{2}{3}$ mile wide, at an elevation of 691 feet above sea-level, in a somewhat open and wind-exposed position among grass-covered mountains. Its shores are treeless, except for a plantation around a small fishing lodge at the south-west end, below Craigronald. The water is very clear, and but slightly peaty. The shore is rocky, with the exception of numerous bays of white syenitic sand. The exposed littoral rocks bear a number of common Bryophytes and lichens, but to no great extent. The aquatic flora is very poor in species, and the semi-aquatic plants of the shore are also poor in species and in numbers, the greater portion of the shore being almost devoid of such plants. Juncus alpinus, *Vill.*, and a dwarf xerophilous form of Heleocharis palustris (p. 181), grow upon the drier parts of some of the sandy bays. In certain of these bays the copious sand is blown up into miniature dunes, capped with Calluna, etc., and resembling a sandy sea-shore on a small scale. The bottom is for the most part very rocky, but there are considerable areas of sand or gravel extending from the margin to a depth of 8 or 10 feet. These areas are usually covered more or less with some of the bottom-carpeting species, Littorella lacustris, Lobelia Dortmanna, and Isoetes lacustris being the most abundant. All these plants are here overgrown to a great extent with Algæ (p. 191). These plants, however, bear no external evidence of injury by the Algæ; but Nardia emarginata and Scapania undulata, both of which grow abundantly on submerged rocks, were much injured by the dense growth of such epiphytes upon them. In some parts, particularly at the south end, Sphagnum subsecundum and Heterocladium heteropterum (p. 188), mixed with Scapania undulata, were very abundant at the bottom from 2 to 8 feet deep—an uncommon situation for such plants. They may have been brought into the loch by one of the burns in time of spate, and then become adapted to the submerged environment. I could obtain no evidence of the existence of living plants in this loch beyond a depth of about 10 feet, not because of the presence of vegetable detritus nor of the opacity of the water, but because in deeper, and often in shallower water too, the bottom is very rocky. I have noticed in many lochs that a rocky bottom is nearly always destitute of the higher plants, that is, when the bottom could be seen or felt with a pole having teeth at the end, or with a heavy hook attached to a line. By bumping such instruments over the bottom of a loch, the vibrations carried to one's hand up the wood or cord give an indication of the constitution of the bottom—mud, sand, gravel, rock, etc. Dredging over a rocky bottom is, of course, impossible, leaving out of the question the certainty of losing the apparatus.

Loch Fleet is a somewhat oval sheet of water, surrounded by treeless hills, and situated about a mile east of Loch Grennoch. It is about a third of a mile long, and is 1113 feet above sea-level. The margin is rocky, and there is very little shore suitable for the development of littoral phanerogams. The water is clear, and but slightly peaty. The flora is scanty, and is restricted to the common types found at Loch Grennoch.

Loch Skerrow is situated amongst wild, rocky moorland scenery, four miles east of Loch Grennoch, at an elevation of 414 feet above sea-level. It is a shallow loch, with a very rocky shore, and with clear, slightly peaty water. Its bottom is covered with rocks, which frequently rise above the surface of the water. The larger of these island-rocks are often capped with vegetation of the moorland type, such as Calluna vulgaris, Vaccinium Myrtillus, etc. More numerous are the rocks which rise to just below the surface of the water. These necessitate caution in navigating a boat, and obviously such a rocky bed greatly hinders dredging operations. Sandy portions of the bottom, down to 12 feet deep, bore an abundant vegetation, but of limited variety; otherwise there was little to be noted excepting at the margins and in shallow, sheltered bays. Many of the shore rocks were covered with a luxuriant growth of lichens, particularly with Parmelia omphalodes. Noteworthy also was the abundance of Bryophytes upon the littoral rocks, and in damp places.

Loch Stroan.—The Airie Burn, which flows from the north-east corner of Loch Skerrow, joins the river Dee after flowing northwards for about two miles. Thence the Dee, impetuous nearer its source, slowly meanders deep and wide through a flat alluvium, eastwards, for about a mile and a half, and then it flows into Loch Stroan. The north-west shore of this loch consists chiefly of sandy or muddy flats, the result of the detrital matter brought into it by the river Dee; this is continuous with the extensive alluvial flats through which the river flows before entering the loch, and is overgrown near the water with Carex rostrata, etc. Farther away from the loch the drier portions are covered with moorland herbage of the grass-like type. Elsewhere the shores are stony or rocky, with a gentle inclination, merging gradually into grassy or heathery moor. Although slightly peaty, the water is clear and bright, so that vegetation at the bottom may be observed at a depth of 10 feet. Spongilla fluviatilis and Anodonta cygnea are both abundant in this loch. The bottom of Loch Stroan is to a great extent sandy or muddy, but no living vegetation occurs at a greater depth than 20 feet, as one might expect would be the case from a consideration of the clearness of the water. The reason is that beyond a depth of 15 to 20 feet the loch bottom is covered with the remains of grass-like moorland vegetation brought into the loch by winter floods as at Loch Doon (p. 219). The dead remains do not come so near the surface here as at Loch Doon, because of the scour caused by the river Dee in flood-time. In this case the bulk of such material is derived from the flat, marshy ground extending a few miles to the west of the loch, through which the river flows. On the east shore of the loch there is a great bank of such dead material, that has been deposited high above the normal water-level; this, like that at the bottom of the loch, consists chiefly of the common moorland and marsh species of Carex, Scirpus, and Molinia. This loch has an abundant and varied flora, and a number of uncommon plants occur plentifully.

Loch Whinyeon is somewhat circular in outline and about half a mile in diameter, occupying an exposed position over 700 feet above sea-level, three miles north from Gatehouse of Fleet. The water is clear and but very slightly peaty. The shore is everywhere stony or rocky, and consists chiefly of broken shale, the beds of which are frequently very highly inclined. The flora of the shore, as well as of the water, is extremely poor, but a number of Bryophytes clothe the littoral rocks.

Lochenbreck Loch has a rhomboidal outline, each side being about a quarter of a mile long. It is situated at an elevation of 651 feet above sea-level, about seven miles N.N.E. from Gatehouse of Fleet, and has the characteristic features of a bare highland loch, modified by a plantation of coniferous trees on its eastern shore. The shores are stony, and the water is clear and slightly peaty. The flora is of the ordinary type, excepting an abundance of Heleocharis multicaulis.

Woodhall Loch is three miles north-east of the last-mentioned. It is $1\frac{3}{4}$ miles long by $\frac{1}{3}$ mile broad, at an elevation of 173 feet above sea-level. Being somewhat wind-sheltered by low hills and surrounded by meadow, grassy moor, or deciduous wood, it presents the general features of a lowland loch, saving that its water is very slightly peaty. Here and there a gravelly bay occurs, but frequently the moor or meadow-land abuts upon the water without the intervention of a shore. Where a strip of shore does occur, it is narrow, stony, and frequently covered with Juncus articulatus. The west side has a reedy or sedgy margin almost continuous throughout its length, but on the east side the reeds are mostly restricted to the bays. At either end there are large associations of Equisetum limosum; the specimens of this plant at the north end are very large, rising 3 or 4 feet out of water 6 feet deep. The bottom of this loch, from a depth of about 8 feet to the deepest part, is covered with the dead remains of vegetation, which prevents the growth of plants upon the bottom at a greater depth than 8 feet.

At some parts of this loch the following successive zones of plant associations were observed, starting from the shore:—(1) Juncus effusus, J. lamprocarpus, J. acutiflorus, and Ranunculus Flammula, all more or less mixed; (2) Carex rostrata or C. filiformis; (3) Heleocharis palustris; (4) Phragmites communis; (5) Equisetum limosum; (6) Scirpus lacustris; (7) Potamogeton natans, P. polygonifolius, and P. lucens, mixed; (8) Nymphæa lutea, Castalia speciosa, and Potamogeton natans, mixed; (9) carpeting the bottom below these zones, wherever there was space, Lobelia Dortmanna and Littorella lacustris.

This loch forms a somewhat transitional stage between a typical peaty highland loch and a typical lowland one.

Blate's Mill Loch is a small circular pool within a few hundreds of yards of the east shore of Woodhall Loch. It is surrounded with a zone of Carex rostrata and Equisetum limosum, with quantities of Nymphæa lutea, Castalia speciosa, and other plants common to the district.

Mossdale Loch is a peaty pool half a mile from New Galloway railway station. It contains a few plants common to the neighbourhood, but, like the last-mentioned, appears to be of no further botanical interest.

Loch Ken is one of the largest lochs in this part of Scotland, being only exceeded in size by Loch Doon. The loch proper is generally considered to lie between the grounds of Kenmuir Castle and the Boat of Rhone railway viaduct; this portion is 4¼ miles long by ½ mile wide. The river Dee joins the loch a little below the viaduct, and is continued as a narrow lake, in some places, however, half a mile wide, considerably to the south of Crossmichael. This lake-like portion extends the loch a further distance of over 4 miles, and is usually recognised as a part of the river Dee, although to the uninitiated it belongs to Loch Ken, and must be considered so from a botanical point of view. This sheet of water is thus about 8½ miles long, and varies in width from a hundred yards to half a mile. Like Woodhall Loch, Loch Ken presents a mixture of the highland and lowland types of lochs, not only in its flora and physical conditions but also in scenic effect. At the head of Loch Ken the slight peatiness of the water is modified by the drainage received from the villages and cultivated areas through which the Water of Ken flows. Both in the species and in the luxuriance of the vegetation at the northern end of the loch, there is evidence of a greater supply of food-salts than is usual in peaty lakes. The water, although slightly peaty, is clear. In many places the shore consists of stones and rocks, which are usually angular or but slightly water-worn, and afford support to a very scanty flora. A narrow strip of such shore usually passes at once into meadow, moor, or woods. In other places the loch is bordered by bog, which makes it difficult to distinguish any line of demarcation between land and water. More rarely the shore may be sandy, or the water may be bordered by a bank without the intervention of a shore. In that portion of the loch above the railway viaduct vegetation seldom occurs at a greater depth than 6 or 7 feet; beyond that depth clay, mud, or vegetable detritus covers the bottom to the exclusion of living plants. In the lower portion, about Parton and Crossmichael, there is in places a bottom flora down to a depth of 12 feet. This is accounted for by the great body of peaty water from the river Dee scouring the bottom and washing vegetable detritus either into deeper places or down stream. It is also interesting to note that Isoetes lacustris, a plant very impatient of water rich in normal plant food-salts, was not found nearer the head of Loch Ken than the vicinity of Burned Island, whence it occurred, but quite sparingly, down to the viaduct; after the loch had received the water of the river Dee, Isoetes became abundant, and continued so down to below Crossmichael. At the head of the loch, where the river Ken and the Knocknairling Burn enter, there is a very considerable area of deposit from the rivers, consisting of gravel, sand, or mud in a more or less marshy condition. These flats are covered with a very luxuriant vegetation, as previously mentioned. There were great masses of Carex rostrata, which could be distinguished at a considerable distance, when blown by the wind, by their glaucous leaves; colonies of Carex vesicaria by their green leaves but otherwise similar growth to C. rostrata; and associations of Carex elatior by their superior height and broad, green, flowing leaves waving in the breeze like a luxuriant field of grain. Then there were large areas covered with a dense jungle of Phalaris arundinacea and Deschampsia cæspitosa growing 4 or 5 feet high, besides a variety of other plants in various places. Nymphæa lutea is very abundant in some parts of the loch, particularly near the head, where the surface of the water is covered for hundreds of yards by its leaves and flowers. Scirpus lacustris grows very luxuriantly throughout the whole area of the loch, and so, in some places, does the ordinary marsh vegetation of the littoral bogs. In some places, especially near the viaduct where shelter from wind is provided by adjoining woods and by the narrowness of the loch, Ranunculus heterophyllus covers the surface of the water with its white flowers and floating leaves, forming one of the characteristic features of this portion of the loch. Occasionally a dry stony shore is overgrown with a large prostrate form of Ranunculus Flammula which roots copiously at the nodes; this is probably the R. radicans of Nolte.

From the viaduct to below Crossmichael the general features are somewhat similar, but, being more remote from hills and moors, the lowland type becomes quite assertive and the gently inclined shores quickly merge into meadow-land or bog. Here again Scirpus lacustris occupies large areas of the margin; there are also large associations of Phragmites communis, Equisetum limosum, Heleocharis palustris, Carex aquatilis, C. rostrata, C. vesicaria, C. Goodenovii, etc. A large barren form of either Nitella opaca or N. flexilis occurs abundantly about and below the embouchure of the Dee; this variety is also found in Woodhall Loch, and was probably transported from there by water, as the effluent of Woodhall Loch flows into the Dee near New Galloway railway station. Near Burned Island there are vast beds of Nitella opaca, but it does not extend beyond a depth of 7 feet. Bryophytes are generally scarce, and in many places even absent altogether from the littoral zone. The most favourable place for such plants is about the north end of the loch, and there a number of species occur on the shore, including a few rarities. Filamentous Algæ are scarce. For the long list of plants found at this loch the original paper must be consulted.

Barscobe Loch is about three miles north-east of New Galloway. It is about a quarter of a mile long, and is situated in the midst of a treeless, hilly, grass moor, which everywhere meets the water, so that there is no shore. The water is quite clear and scarcely peaty. On the east side there are thin beds of Carex rostrata. On the west side there are associations of Scirpus lacustris and Carex rostrata. On grassy bogs, which occur here and there at the margin, the usual bog plants occur. Nothing of particular interest was noticed at this loch.

Loch Brack is a mile north-east of Barscobe Loch, and is similar to it in general features, but smaller. Between the grass moor and the water a narrow zone of Juncus acutiflorus intervenes more or less all round the loch. An average number of common plants occur, but nothing of special interest was observed here.

Loch Howie is two miles north-east of Barscobe Loch, and is larger than it, being three-quarters of a mile long, but very narrow. In general features it again resembles Barscobe Loch. There are associations of Phragmites communis and Scirpus lacustris, whilst Carex filiformis occupies situations usually taken up by C. rostrata. A number of common plants occur here, but nothing of special interest was noticed.

Loch Skae is a small oval loch about a quarter of a mile long, situated half a mile east of Loch Howie. The general flora is similar to that of the three lochs just mentioned, but the physical features are different. The surrounding moors have more heather and peat; the scenery, particularly on the east, is rocky and wild; the water is a little more peaty, and the east shore is rocky or stony. Isoetes lacustris, Utricularia intermedia, and Potamogeton polygonifolius are more abundant here than at the other three lochs. The rocks on the east shore are overgrown with mosses, chiefly Hypnum cupressiforme and Rhacomitrium aciculare. About the margin there are associations of Phragmites communis, Carex rostrata, and C. filiformis.

Lochinvar is four miles north-east of Dalry. It is about half a mile long and one-third of a mile wide, and is situated at an elevation of 737 feet above sea-level in a depression of a hilly, grass and heather moor. The scenery around is bare, desolate, and, with the exception of a few conifers about the gamekeeper's house, treeless. The water is very clear, and but slightly peaty. Generally the moorland vegetation approaches almost to the water's edge, so that there is practically no shore. The bottom is rocky nearly everywhere, and, with the exception of a few species which are abundant in some parts, the flora is extremely poor. There are no formations of marsh plants about the shores; such of these plants as do occur are either as scattered specimens or in a few very small groups. The submerged plants are more interesting, although these too are very poor in species; yet four species of Potamogeton are abundant in some places.

Loch Dungeon is seven miles north-west of Dalry, at an elevation of over 1000 feet above sea-level. Beautifully situated at the base of rocky and precipitous mountains, it forms a magnificent, although a treeless, piece of highland scenery, wild in the extreme, particularly on the south and west shores, where the mountains rise almost perpendicularly from the water's edge. This loch is irregularly shaped, being almost cut in twain at one part by a rocky promontory from the south shore and by gravel from a moraine, washed into the loch by a burn, forming a peninsula from the north shore. The loch is about a mile long by a quarter of a mile broad, and is 94 feet deep. Its water is extremely brilliant and clear, and its shores are mostly rocky or stony. Excepting associations of Equisetum limosum and Phragmites communis in some of the bays, the littoral flora is very scanty. The submerged rocks about the shores, as well as those exposed, frequently exhibited a wealth of Bryophytes. The submerged phanerogams were not very abundant, there being merely a few of the common species.

Loch Minnoch is a mile north of Loch Dungeon. It is only a quarter of a mile long, but is beautifully situated amidst rugged hills. The water is very clear, being, in fact, the water of Loch Dungeon which flows into it by the Hawse Burn. This burn, which enters the loch on its south side, has brought into it a large amount of detrital matter, causing a shallow area and a considerable bog on that side of the loch. This shallow area is overgrown with Equisetum limosum, etc., whilst the bog, which is covered with appropriate vegetation, merges imperceptibly into moor. The west shore is peaty, and it, together with the south shore, forms a suitable habitat for a considerable number of plants of the marsh type. The north and east shores are rocky, and bear a very scanty vegetation. The submerged phanerogams appear to be poorly represented by a few ordinary species. A number of Bryophytes are common on the shore rocks, and a curious form of Catharinea undulata covers rocks to the depth of a foot or more.

Loch Harrow is rather larger than the last-mentioned, and about half a mile north of it. The shores are more stony, and there are fewer associations of littoral plants, otherwise it is similar.

The moor about the three last-mentioned lochs is mostly covered with grass-like associations, Molinia cærulea being the most abundant.

The three last-mentioned lochs agree, in the paucity of their flora, with those on the Merrick range a few miles to the west. The scarcity of water-birds about these and other mountain lochs is probably a factor to be considered when forming a theory to account for the poverty of species in the flora of such lochs. Doubtless mountain lochs offer but an inhospitable asylum to the majority of our water-fowl. That such birds are active agents in the distribution of aquatic plants is beyond doubt. They are also great destroyers of the less robust vegetation, especially in shallow water, and are frequently the cause of the sudden disappearance of an association of plants from some particular part of a shore. To cite an example: I have known Scirpus setaceus quite obliterated from a sandy shore, whilst other plants new to that lake were introduced; and such changes amongst the minor associations of plants are constantly occurring.

Area V

Having now passed by a circuitous and zigzag route over the majority of the lochs situated in north-west Kirkcudbrightshire, where the highland type predominates, let us examine south-east Kirkcudbrightshire, where many of the lochs are lowland in character. This district is almost wholly devoted to agricultural pursuits. The land is frequently very rich, and the farmers are prosperous and noted for their wealth. The undulating and often well-wooded country is frequently beautiful. There are no large towns, but the country is studded with numerous villages, and, for an agricultural district, it is well populated. There are comparatively few lochs, and we may begin their inspection at Loch Corsock, and passing over the Area by way of Lochs Erncrogo, Glentoo, Carlingwark, and Lochaber, finish our tour at a group of small lochs lying to the south of Dalbeattie. The original paper contains thirteen illustrations of the lochs, etc., of this Area.

Loch Corsock is a somewhat triangular sheet of water situated in an upland district, whose moorland character has been modified by cultivation. It is six miles north of Crossmichael, at an elevation of 540 feet above sea-level, and the water is somewhat peaty. The western shores are flat and muddy or peaty, and have an extensive vegetation, whilst the eastern shores are rocky and stony, with only a few plants. On the south-west side there is an extensive marsh, now partially drained. The west, north, and north-east sides are clothed with coniferous wood, and there is also a small plantation of the same kind on the south side. The loch is therefore wind-sheltered to a considerable extent, although open to the south-west. Alisma ranunculoides was abundant, and many specimens were flowering at a depth of 3 feet below the surface, as well as the normal terrestrial form about the margins of the loch. A considerable number of phanerogams grow here, but, save for a few abundant species, Bryophytes are scarce.

Loch Roan is a somewhat triangular sheet of water two miles north of Crossmichael. The west, north, and east margins are clothed with wood, chiefly coniferous, to the water's edge; whilst the south shore abuts upon meadow-land. Where the shores are gravelly or muddy there is little vegetation, but where boggy the usual marsh plants occur. This is the reservoir for the water supply of Castle-Douglas, and presents little of botanical interest beyond a few common plants, such as associations of Carex rostrata and Equisetum limosum upon the south shore. There were, however, two unusual members of a shore flora, namely, Hypericum humifusum in dry places, and Anagallis tenella on wet sand.

Loch Erncrogo is about a mile north-east of Crossmichael. It is a small loch of the lowland type, about one-third of a mile long, and, being more or less surrounded by marsh, there is little shore. Outside the zone of bog, rich agricultural land prevails, excepting on the west side, where there is a plantation of conifers. The chief features here are the great colonies of Carex rostrata, beyond which the shallower areas of the loch, particularly at the north end, are overgrown with Castalia speciosa, Nymphæa lutea, and Equisetum limosum. A large number of other plants grow here also, but usually more or less intermingled with one another, and not in definite and distinct associations, as frequently happens with some species. This, I suppose, is due to the gentle inclination of the boggy shore towards the water, and to the general conditions being equally agreeable to many species, without being particularly favourable to a few only.

Loch Dornell is also a small loch, and occupies a somewhat exposed situation in an agricultural and moorland district two miles west of Crossmichael. The water is very clear, the shores are stony, and, besides associations of Carex rostrata and Phragmites communis in the bays, there is no great development of the littoral flora. Nearly everywhere the stony shore has a thin, narrow zone of Juncus articulatus, often mixed with Ranunculus Flammula, at the margin of the water.

Meikle Dornell Loch is a small circular pool, half a mile west of the last-mentioned, and connected with it by a burn. This little loch is surrounded by low hills, and the water is bordered by peaty banks, so that no shore intervenes between it and the moor. It is almost surrounded by a belt of Phragmites communis. There are also a number of other common plants.

Loch Glentoo is four miles west of Castle-Douglas. It lies in a hollow of the moor, and appears to have occupied a much larger area at one time, if one may judge by the extent of low marshy ground around it. The margins of this loch are treeless, and its water is peaty. From the north and west shores outwards, the loch is half overgrown with great beds of Phragmites communis mixed with

Scirpus lacustris, and about the shores Carex rostrata and C. filiformis abound. About the south-west end the growth of marsh vegetation is very dense, and merges gradually into moor through an area of bog. Occasionally the shore is stony, but generally only a peaty bank divides the water from the moor. The flora resembles that of the next loch.

Loch Bargatton occupies an open position on the moor, half a mile south-west of the last-mentioned. It is somewhat circular in outline, and the water is peaty. The eastern shores are stony and rocky and comparatively bare of plants. The western side is overgrown with dwarf Phragmites communis, which also occurs in bays at other parts of the loch. This loch and Loch Glentoo, although at an elevation of only about 200 feet above sea-level, resemble lochs of a highland type in their floras, because of their exposed position on the open moor and their peaty water.

Carlingwark Loch forms a pleasing addition to the prosperous little town of Castle-Douglas. The loch is connected with the river Dee by a narrow canal, which is about a mile and a half long. This canal was cut for the transport of marl up the river Dee, even as far as the Glenkins. Marl was discovered in abundance in and about the loch, and was formerly in great demand by agriculturists for fertilising their land, instead of lime. There are several islands wooded with poplars, willows, alders, etc., which add to the picturesque appearance of the loch. An unpleasing feature is that the sewage of the town is drained into the loch, which, although about 105 acres in extent, is very shallow, except at the sites of the old marl-pits, so that in hot, dry summers the residents of the town are inconvenienced by unpleasant odours and the risk of disease. The water at the south end is fairly clear and bright, but at the north end it is somewhat turbid and dead-looking, which is probably the result of the drainage from the town. The vegetation also has doubtless been affected thereby, for the semi-aquatic flora is composed of a large number of species, most of which grow in great luxuriance; whilst the submerged aquatics, although extremely abundant, are restricted in variety, possibly because the abnormal abundance of food-salts in the water, combined with the general shallowness of the loch, has favoured the excessive increase of a few species to the exclusion of others. I have, in fact, seen few lakes with such exuberant vegetation as occurs here. The margin is frequently marshy, and overgrown with a dense growth of reed or sedge, particularly in the south portion of the loch. At other places, especially at the northern end, the flat shore is either stony, or of muddy sand, and nearly everywhere such shores are covered near the water with Cladophora flavescens, mixed with Œdogonium, Spirogyra, etc., and the same species float on the surface of the loch, occupying large areas in sheltered bays. Such floating Algæ are a constant feature in lowland lochs where the water is polluted with sewage. Many submersed plants had a deposit of calcium carbonate upon their leaves, particularly Myriophyllum spicatum. Fresh-water mussels occur in extraordinary abundance in various parts of this loch, some of the specimens measuring 7 inches in length. The roots and rhizomes of numerous plants, especially Glyceria aquatica, were frequently found covered with the young of these molluscs. The shallow portions of the south end of the loch are being rapidly encroached upon by the marsh vegetation, if one may judge by the wide area of bog, which in turn is being converted into meadow-land by the accumulation of the remains of plants that grow there. It would be very instructive to have a series of exact measurements, from various lochs, extending over a number of years, in order to show the rate of this encroachment upon the water, together with the rate of conversion of the bog behind into *terra firma*. A feature of this loch is the vast quantity of Potamogeton Friesii that chokes the loch in some parts. A number of other rare plants occur in abundance, together with the more usual species, for a list of which the original paper may be consulted.

Auchenreoch Loch is six miles north of Dalbeattie. It is a mile in length, with a maximum breadth of nearly one-third of a mile, and is surrounded by agricultural land. The water is clear and not peaty. The main road from Dumfries to Castle-Douglas adjoins the east shore of the loch throughout its length. At the north-east end there are associations of Scirpus lacustris standing out in the water; nearer the shore a large area is covered with Phragmites communis, behind which there is a marsh with the usual plants. These conditions extend for some distance down the loch towards the south-west end. At other places there is a narrow strip of stony shore with meadow beyond, or there is scarcely any shore, grass land coming down quite to the water.

Milton Loch is about a mile east of the last-mentioned. It is about a mile long by half a mile wide, and is surrounded by agricultural land. The water is clear and not peaty. The shores are flat and stony, and merge imperceptibly into meadow or arable land, except where bordered by trees or public roads. There are no associations of marsh plants entering the loch; such as occur are merely a few species as stragglers over the stony shore, Alisma ranunculoides being one of the most abundant. Chara fragilis, var. delicatula, and Chara aspera, var. subinermis, are abundant on the bottom of the loch.

Lochrutton Loch is three miles east of Loch Milton, and is three-quarters of a mile in length, with a maximum breadth of half a mile. This loch is the reservoir for the water supply of Dumfries, and the water is clear, not peaty. An extensive, deep marsh at the south end, which has been cut off from the loch by a dam, is overgrown with common plants. The shores of the loch are mostly stony, and it is surrounded by cultivated land. It presents very little of botanical interest. The three last-mentioned lochs occupy bleak, wind-exposed situations in an area of active agriculture, and the scenery around is tame and uninteresting.

Lochaber Loch is eight miles north-east from Dalbeattie. It is surrounded with low hills, the lower slopes of which are wooded, chiefly with coniferous trees, to the water's edge, excepting on the west, where the country is open and agricultural land prevails. The water is slightly peaty, and the marginal flora is poor in variety. At the south-east end there are associations of Scirpus lacustris, Equisetum limosum, and Carex rostrata, none of which grow so tall and luxuriant as might be expected from the lowland situation. At the west side, where the shore is boggy, there are associations of Phragmites communis, but the specimens are dwarfed, also of Carex rostrata, Equisetum limosum, Castalia speciosa, and Menyanthes trifoliata. Otherwise the somewhat flat and stony shores are either bare of vegetation, or sparsely clothed with a few common plants.

Auchenhill Loch, which is four miles south of Dalbeattie, is the smallest of a group of four lochs. It is about a quarter of a mile long by one hundred yards wide, and is a typical lowland pool situated amidst pleasant pastoral scenery. There are no trees at its margin, but it is more or less surrounded by a zone of Phragmites communis, behind which there is a border of marsh merging imperceptibly into meadow. In front of the Phragmites a belt of Castalia speciosa almost encircles the loch, and behind the former an area of bog, overgrown with the usual marsh plants, surrounds the whole.

Barean Loch is about half a mile east of the last-mentioned, but it is considerably larger, and has an irregular outline. The water is rather peaty. It is picturesquely surrounded by low hills, some portions of which are cultivated, while the remainder consists either of moor or of wood; the margin of the loch is also well wooded. It is more or less surrounded by a sedge or reed marsh, composed chiefly of the following species:—Scirpus lacustris, Phragmites communis, Equisetum limosum, and Carex rostrata. A number of common submersed aquatics occur in the water, amongst which may be especially mentioned Apium inundatum, because it grows here to a depth of 7 feet, and reaches the surface from that depth, although in such deep water it does not fruit freely.

Clonyard Loch is a quarter of a mile south-west of Barean Loch; it is smaller, but the features are somewhat similar. It is surrounded by a sedge or reed swamp composed chiefly of Scirpus lacustris and Carex rostrata; there is also an association of Typha latifolia, as well as minor colonies of Phragmites communis and Equisetum limosum. In the water outside the swamp zone there is a broad belt of Castalia speciosa.

White Loch is the largest of this group, being about half a mile long by a quarter of a mile broad. It is half a mile south-east of the last-mentioned, and the public road from Douglas Hall to Dalbeattie adjoins its western shore. The neighbouring district is a mixture of moor, cultivated land, and plantation, and the water is rather peaty. Where not marshy, the shores are sandy or stony, with a few syenitic rocks. It is a little more than 100 feet above the level of the sea, which is about a mile distant, and, although distinctly lowland in general aspect, yet a number of plants usually associated with peaty highland lochs flourish here. This is probably because the loch has not been interfered with, whilst the surrounding moor has been brought under partial cultivation. Littorella lacustris, Lobelia Dortmanna, Isoetes lacustris, Nitella opaca, and Fontinalis antipyretica, for example, all grow in this loch. Phragmites communis forms a belt around a great portion of the loch, especially on the east. On the west side there is a large association of Typha angustifolia, as well as minor groups of the same at other parts of the loch. In the water, beyond the Phragmites and Typha, associations of Scirpus lacustris occur, whilst Carex rostrata and Equisetum limosum occupy other sites.

At none of the lochs of this Area (V.) was there any particular abundance of Bryophytes, such as occurred about the lochs of Area IV.

Area VI

Wigtownshire is remarkable for its great tracts of monotonous, treeless, and dreary peat moor. In comparison with the adjoining Kells district, almost the whole county appears flat and tame. The relaxing and enervating atmosphere of south-east Kirkcudbrightshire is here in many places intensified. Agriculture is the dominant industry, particularly dairy-farming, and beyond the intractable moss-hags the land is frequently very rich. The population is chiefly centred in the areas of agriculture. The extensive moors are but thinly peopled, and there are no large towns. Those sheets of water that are situated on the open moors resemble highland lochs in their general features, although none that I have visited are at a greater elevation than 400 feet above sea-level. Those lakes that are within the zone of active agriculture are decidedly of the lowland type.

Stormy weather considerably hindered work, so that during the time at my disposal I was unable to visit some of the lochs situated in outlying places, and difficult of access under any conditions. In particular I regret having to omit those in the north of the county, within and without the Ayrshire border, because these are less likely to have undergone alteration by the hand of man. We will begin the examination of the lochs of Wigtownshire at Black Loch, which is north of Kirkcowan, and take a zigzag course westward until we finish at the lochs that are situated in the neighbourhood of Stranraer. In the original paper there are twenty-four illustrations of the lochs, etc., of this Area.

Black Loch is the smallest of a series of three, and is situated five miles north-west of Kirkcowan. It is about a quarter of a mile long, is surrounded by a treeless moor, and its water is rather peaty. The only strip of shore is at the east end; elsewhere a bank of peat separates the water from the moor. The aquatic plants are chiefly at the west end of the loch, and bottom-carpeting species, such as Littorella lacustris, are scarce. About the margin there are associations of Phragmites communis, Scirpus lacustris, Equisetum limosum, Carex rostrata, C. filiformis, and Castalia speciosa. There are a few common mosses on the shore rocks at the east end, otherwise Bryophytes are scarce.

Loch Heron is a somewhat rectangular sheet of water, nearly as large again as the last-mentioned, and situated half a mile to the south-west of it. There is a plantation of conifers upon the south and east shores; otherwise it is surrounded by cultivated land or moor. The water is clear and slightly peaty. The shores are stony, or in some places there is a peat bank entering the water without the intervention of a shore. There are scattered associations of the following plants about the margin:—Phragmites communis, Carex rostrata, Scirpus lacustris, and a few sparse patches of Equisetum limosum. Littorella lacustris and Lobelia Dortmanna carpet the bottom in places, and there is a fair number of other submersed aquatics.

Loch Ronald is close to the last-mentioned, and is about a mile long. There is a plantation of conifers on the east side, otherwise it is surrounded by agricultural land or moor. The water is very clear, and the shores are stony, flat, and from a botanical aspect almost featureless, much resembling Loch Ashie in Inverness-shire. Here and there a bank of peat 8 or 10 feet high dips into the water without the intervention of a shore. There are two small associations of Equisetum limosum and one of Scirpus lacustris, all at the south-west end, and groups of Carex rostrata in the effluent. I was not able to obtain the use of a boat, because it had been previously engaged; but a close examination of the barren shore, for the remains of submersed plants, suggested a scarcity of vegetation in the water. Although these three lochs possess a fair number of plants between them, yet they are not of much interest botanically, so far as I could find.

Clugston Loch is a small sheet of water three miles south of Kirkcowan, with slightly peaty water, and surrounded by moor. The shores are rocky or peaty, and, beyond colonies of Carex rostrata, C. Goodenovii, and Equisetum limosum, there are no large associations of semi-aquatic plants. A number of other common species flourish on the shores and in the water.

Loch Wayoch is the most northerly of a group of lochs situated on a dreary, boggy moor, many miles in extent. The last-mentioned loch is indeed upon the same moor, but at its outskirts, where the ground is less boggy, whilst the scenery is enlivened eastwards by the adjacent area of cultivation. An old resident informed me that during his life the view of the country beyond the moor (*i.e.* looking from Anabaglish southwards) had been considerably curtailed owing to the gradual elevation of the intervening moss.[1] Exact measurements of such development over a long period would not be without interest.

This loch is four miles south-west of Kirkcowan, and is a somewhat circular pool 200 yards across. There is no shore, the water being surrounded by deep bog differing only from the moor in being more ready to engulf the unwary. I succeeded in getting within a few feet of the water, and was surprised to find that it was beautifully clear and apparently not peaty. Another interesting fact was the presence of an association of Typha latifolia, a plant usually associated with the evil-smelling mud of lowland lakes rather than a lochan in the midst of a peat moor. Other uncommon members of the marginal flora were Cladium Mariscus and Hypericum elodes, while the bulk of the encircling vegetation was composed of a variety of the usual species. Amongst a number of Bryophytes that flourished in the surrounding bog, the interesting Cephalozia Sphagni was abundant. On the drier parts of the bog Calluna and Myrica have spread from the adjacent moor, where Cladonia uncialis occurs in extraordinary abundance.

Fell Loch is larger than Loch Wayoch and half a mile south-east of it. The water is peaty and the bottom is of peat. A number of plants common to the district occur in it.

Black Loch is close to the last-mentioned and similar to it, but the water is not so peaty, and there is less vegetation. Cladium Mariscus and Carex filiformis are abundant here, amongst other commoner plants.

[1] A wet moor with much Sphagnum, etc., is frequently called a moss.

Mochrum Loch is half a mile south of the last-mentioned, but is much larger, being about one and a half miles long by nearly one-third of a mile broad. The north and north-east sides are wooded, chiefly with coniferous trees. There are numerous islands scattered over the loch; these also are wooded, and give a pleasing feature to the otherwise bare scenery. There is very little shore to this loch, merely a narrow strip of rocks or stones intervening between the water and the moor or wood; neither are there any sandy bays, but occasionally there is a stretch of peaty shore. The outline is very irregular. The loch is very shallow, the average depth being only 7 feet, and the bottom is frequently rocky. Excepting where rocky, the bottom is covered with plants. The water is clear, scarcely peaty, and the bottom can be seen through 7 feet of water even in dull weather. It is difficult to account for the very slight peatiness of the water of this and neighbouring lochs. As they are situated in the midst of a spongy peat moor, one would expect to find the water quite peaty. As no burn of considerable size enters either this or Castle Loch adjoining, presumably they are fed chiefly by springs which may, of course, have no connection with the water of the moor. It is probable, however, that some constituent, such as an alkali, of the underlying rock may neutralise the peat extract, thus rendering the water clear; the presence of certain calciphilous plants, *e.g.* Eupatorium Cannabinum, suggests lime also.

A large number of plants are recorded from this loch in the original paper; some of these are species that are not usually found in lochs on peat moors, and their presence here is no doubt due to the neutralisation of the acid humus in the water. The marginal flora is rather scanty, as there are no large associations of dominant marsh plants. The Bryophytes of the shore, with the exception of Hypnum cupressiforme which covers rocks, and Sphagnum sp. in peaty places, are not abundant.

Castle Loch is half a mile west of the last-mentioned, which it much resembles. There are a few trees at the north end and on one of the islands, which also has upon it the remains of a small castle. The surrounding country is bare, open moor. This loch is studded with numerous rocky islands, the largest being occupied by cormorants hundreds of which breed there. The shores are rocky, and the bottom is rocky nearly everywhere. The water is clear like that of Mochrum Loch, and the average depth is $6\frac{1}{2}$ feet. I carefully examined the bottom of this loch, as well as the stormy nature of the weather would allow, but could obtain no plants from the water, save Fontinalis antipyretica and F. squamosa, which are abundant on the rocks. The bottom appears to be quite destitute of plants, save the two species just enumerated. This is remarkable, especially when the

16

adjoining Mochrum Loch has such an abundant aquatic flora. Mr David M'Dowall, the keeper, informed me that he had never seen any plants upon the net when netting the loch. The water was remarkably free of plankton organisms, the tow-net gathering extremely little (end of August), but Mr M'Dowall told me that in early summer the water is thick and green with some organism that dies away towards the end of July. Perhaps the presence of this organism in the spring accounts for the absence of plants in the water. The scanty vegetation of the rocky shore was of no particular interest, being similar to that of Mochrum Loch, but less abundant. Lythrum Salicaria and Phalaris arundinacea were the most plentiful species.

On Anabaglish Moss, to the north-west of Castle Loch, there are a number of small lochans of some interest, because of the abundance of their vegetation, which includes some unusual species—Cladium Mariscus, Schœnus nigricans, and Hypericum elodes being abundant.

[**Monreith Lake**, near Port William, is entirely surrounded by wood, affording shelter to many rare species of water-fowl. In addition to the usual marsh and aquatic plants, which grow here very luxuriantly, this lake is becoming choked up with Anacharis Alsinastrum.—J. M'A.]

[**Dowalton Loch**, near Sorbie, was once an extensive sheet of water, but about sixty years ago it was almost emptied by cutting a deep outlet at its eastern end. Since then it has become overgrown with a dense growth of marsh plants, but cannot yet be said to be of much use agriculturally.—J. M'A.]

[South of Whithorn are numerous small lochs becoming gradually overgrown with vegetation, amongst which several uncommon species of Carex may be found. Further south, and to the west of the Isle of Whithorn, there are several small lochs in which grows the beautiful Chara polyacantha.—J. M'A.]

Barhapple Loch is four miles east of Glenluce, on an extension of the same moor as Castle Loch is on, from which it is distant about four miles. It is a circular loch, about a quarter of a mile across, with dirty, peaty water. The north side is bordered by a dense association of Phragmites communis, whilst the same plant occurs scattered over the peaty and muddy south shore. On the west side there is a considerable extent of marsh, dominated by Carex rostrata, C. filiformis, etc. On the east the shore is peaty or gravelly, and is bordered by a bank of peat 4 to 6 feet high. Interesting forms of Juncus bufonius, J. supinus, and Peplis Portula occur on the south side. There were very few mosses and no hepatics about the shores of this loch.

Loch Dernaglar, half a mile south of the last-mentioned, is somewhat circular in outline, and about a third of a mile across. The moor around is flat and treeless, and the water is peaty. Banks of peat usually separate the water from the moor, but occasionally the shore is stony or is formed of flat rock, particularly on the east side, which is rather bare of littoral vegetation. The western margins are marshy, especially near the affluent, and support a considerable vegetation, associations of Scirpus lacustris, Phragmites communis, Carex rostrata, C. filiformis, and C. Goodenovii being dominant. Amongst other plants, Pilularia globulifera, Subularia aquatica, Heleocharis multicaulis and viviparous forms of it, were all abundant here.

Whitefield Loch is three miles south-east of Glenluce. It has an angular outline, is about half a mile long, and is a good deal enclosed by trees, with cultivated land or moor beyond. The water is slightly peaty; the shores are stony, and for the greater part bare of vegetation. The most noticeable feature of the shore flora is the abundance of Lythrum Salicaria. Besides a number of plants usual to the district, I saw nothing here of particular interest.

Barlockhart Loch is a small circular pool about a mile south-east of Glenluce. It is surrounded, excepting on the west, by low hills of the pasture or cultivated types, and the water is not peaty. The loch is enclosed by a zone of Phragmites communis, beyond which, in the water, is an association of Castalia speciosa and Nymphæa lutea, which also extends around the loch, and between the two at the east end an association of Equisetum limosum is interposed. Behind the Phragmites there is a strip of marsh with Salix aurita and Alnus glutinosa in places, as well as a number of the usual bog plants. A curious floating form of Hydrocotyle vulgaris occurred here, and dwarf bushy forms of Potamogeton obtusifolius, as well as the normal forms of both. In the original paper a long list of plants is given for this and the foregoing lochs.

White Loch is nearly a mile long by half a mile broad, and is one of the largest of a group situated about three miles east of Stranraer. White Loch and the adjoining Black Loch are within the private grounds of Castle Kennedy, the seat of the Earl of Stair, and are ornamental waters to Lochinch House, although left as far as possible in a natural condition. They are surrounded by lawns or meadows which are furnished with groups of ornamental trees, an island on the west side of the White Loch being also beautifully wooded. There is no extent of shore anywhere, neither is there any considerable development of marsh vegetation; but here and there narrow zones of marsh plants, 1 to 10 feet wide, intervene between the water and the grassy banks. The water is not peaty, but is so turbid and greenish-coloured that the bottom cannot be seen at a greater depth than 18 inches when looking over the side of a boat (*i.e.* in August).

Plankton organisms are the cause of this turbidity, more especially the diatom Melosira granulata. There is neither affluent nor effluent to this loch, save a shallow boat canal connecting it with the adjoining Black Loch, the water of which is dark and peaty (presumably these facts guided the nomenclator of the lochs). The water is therefore more or less stagnant, a condition favouring the increase of certain plankton organisms. A feature of both this and the Black Loch is the narrow border of Heleocharis palustris that prevails nearly everywhere, growing luxuriantly to a height of 3 feet, with very large inflorescences. Elatine hexandra grows exposed upon the shore, also in the water to a depth of 2 feet. Myriophyllum alterniflorum and M. spicatum both grow abundantly in this loch, which is rather unusual. Amongst several species of Potamogeton a very large form of P. lucens should be mentioned, and a beautiful form of P. crispus with broad leaves which have a wide red midrib; the latter is found in other lochs of this neighbourhood. Bryophytes are scarce.

Black Loch adjoins the last-mentioned. It is over a mile long, but is narrow, particularly at the north-west end. The surroundings are similar to those of the White Loch, but the water is brown and peaty, and, although plankton organisms abound, the bottom can be seen through 3 feet of water when looking over the side of a boat. The shore is similar to that of the White Loch, but the flora is more varied. Usually water from 7 to 10 feet deep occurs within a few feet of the shore. To a depth of about 7 feet a few of the usual plants may be found, but they are by no means abundant, as the bottom is generally stony. At greater depths than 7 feet I obtained no living plants, but an abundance of dead vegetable remains, as at other shallow peaty lochs with no current to scour them. At the north-west end there is a circular basin connected with the loch by a narrow channel. This is almost surrounded, excepting on the south-west side, by a narrow border of Phragmites communis, Typha latifolia, and Scirpus lacustris; whilst the surface is largely overgrown with Nymphæa lutea. At the south-east end of the loch there is a marsh with the usual common plants. Bryophytes are everywhere scarce.

Cults Loch is half a mile east of the last-mentioned. It is a small circular loch, with non-peaty water, surrounded by meadowland. At the north-west and south-east sides there are small bogs; at other places a narrow zone of marsh chiefly occupied by Juncus effusus intervenes between the water and the pasture. There is little of botanical interest here, beyond a number of common plants.

Loch Magillie is about a mile south-west of the White Loch. It is a small oval loch with clear water which is not peaty, and with no visible affluent or effluent. The loch is situated in a hollow, and the meadow-land, which surrounds it on three sides, runs down almost to the water's edge, a narrow strip of stony shore intervening. This shore is chiefly occupied by Juncus effusus, with which a few other plants are mingled. At the south-west side there is a plantation between the loch and the adjacent road. The maximum depth is 14 feet, and the bottom is almost entirely covered with vegetation. Lobelia Dortmanna and Isoetes lacustris are both very abundant, which is surprising when the surroundings are taken into consideration; their presence probably indicates a poor supply of food-salts in the water.

Soulseat Loch is close to the above, but is not connected with it. It has an irregular outline, is about half a mile long and over a quarter of a mile broad. The surrounding features are similar to those of Loch Magillie, as also is the margin. The west shore has a zone of Heleocharis palustris, as at the White Loch, behind which, in some places, there is a narrow strip of marsh, with the usual variety of plants. At other parts a narrow border of stones intervenes between the water and the meadow; this shore, as at Loch Magillie, is occupied by Juncus effusus. The stones from the margin to a depth of 2 or 3 feet are often thickly overgrown with Cladophora canaliculata, etc. A marked feature of this loch is the vast quantity of plankton organisms, which render the water quite turbid, in addition to which there are such enormous numbers of Glœotrichia Pisum that in some parts the water resembles pale green paint. No doubt the turbidity of the water of this loch accounts, in some measure, for the poor bottom flora. The Rev. Mr Paton, whose manse is pleasantly situated on a peninsula jutting into the loch, informed me that in the winter the turbidity disappears, and then it is possible to see the bottom at a depth of 6 feet. Obviously the clearness of the water in winter has no effect upon the extension of a bottom flora of phanerogams. No plants occur at a greater depth than 6 feet; in deeper water there is a deposit of vegetable detritus lying upon mud. Ranunculus circinatus and Callitriche autumnalis are the only dominant submerged phanerogams, and both are extremely abundant. Potamogeton perfoliatus abounds in a few spots; Littorella lacustris and Nitella opaca occur, but not plentifully. No other submerged plants were found. Bryophytes are practically absent, excepting a few of the common marsh species.

There are three small lochs lying close to the railway about a mile west of Castle Kennedy station. The easternmost one is dry, and the site covered with Juncus effusus and other marsh plants. The others are entirely overgrown with aquatic vegetation, and are so surrounded with extensive marsh that the water cannot be approached.

[**Lochnaw** partakes of much the same characteristics as Monreith Lake (p. 242), being also surrounded with wood. Carex pendula grows upon its shores.—J. M'A.]

There are some pools situated upon the Sands of Luce. Thinking, from the nature of the surroundings, that they might afford something of interest, I was disappointed to find they had dried up. In the original paper there is a short note on the vegetation of the Sands of Luce, which extend about six miles along the coast and reach a mile and half inland, the highest dunes being at some distance from the sea. The greater portion of the ground, however, is flat and moor-like, and, in contrast to the almost bare dunes, such parts have a complete plant-covering, the dominant plants being Ammophila arundinacea, Carex arenaria, Salix repens, Hylocomium triquetrum, Rhacomitrium canescens, and its variety ericoides, Calluna vulgaris, and Pteris aquilina. In some places there are grassy swards which are closely cropped by rabbits.

Area VII

In Fife and Kinross a few lochs of a semi-highland character may be found on the higher hills. The greater number of the lochs in this district, however, are distinctly of a lowland type, and many of them have a very rich flora, comparatively rare plants often occurring in great abundance. The central and western portion of Fife is renowned as a coal-producing district, and whilst thousands of the inhabitants enrich themselves by bringing mineral wealth from the bowels of the earth, others, nearly everywhere, are actively engaged in agricultural operations. The rich soil readily responds to the methods of modern farming, and even the less favourable spots are, under the stimulus of scientific treatment, made to grow valuable crops, instead of being relegated to the unproductive realms of sport. Besides this, numerous manufacturing industries are carried on upon a large scale in many places, and the great extent of sea-coast gives occupation to a considerable number of fisher-folk. This Area is therefore a densely populated one, and the greater number of its lochs have had their natural features considerably altered by the hand of man. Suitably situated lakes have been converted into reservoirs for providing the larger towns and villages with water. In some parts, especially in East Fife, the public water supply presents a serious problem that has not always been satisfactorily solved, owing to the comparatively small rainfall and the absence of suitable water in the form of lochs or streams. As an example of this difficulty, it may be mentioned that the water supply for the Newport district is brought across Strath More, the Sidlaw Hills, and the Firth of Tay from Lintrathen in Forfarshire. In some parts new lochs have been created by the construction of dams, etc. In other places shallow sheets of water, that could be put to no useful purpose, have been drained and the sites utilised for agriculture; whilst in a few cases lochs are used as receptacles for sewage. The only lochs of this area that retain their natural conditions are the smaller ones on the Cleish Hills.

The Carboniferous and Old Red Sandstone series of rocks, which largely prevail, have in former epochs suffered considerable contortion from volcanic activities, and large areas are covered with lavas, tuffs, and dolerite sills. Suffice it to mention Burntisland Bin, Largo Law, May Island, and Norman's Law as eloquent monuments of that period. The country is hilly, but not mountainous, yet in many parts the scenery is beautiful. Instance the undulating country to the west of Loch Leven and of the Howe of Fife, or the charming scenic effect produced by the rapid alternation of hill and dale in the neighbourhood of Aberdour, Burntisland, Newburgh, and Newport. Contrast the weird monotony of the flat links of Tents Muir with the bold perpendicular crags of May Island. Contemplate the picturesque grandeur of the Firth of Tay, equalled but not surpassed by the vaster expanse of beauty afforded by the lower reaches of the Firth of Forth. Turn from the grimy atmosphere of the sordid mining villages, and from odoriferous Kirkcaldy, to the wilder portions of the Lomond, Cleish, and the eastern slopes of the Ochil Hills, where one is forcibly reminded that Philistia has not yet completely triumphed over the rural glories of Fife and Kinross.

Our inspection of the lochs of Area VII. may begin at Lindores Loch, in the neighbourhood of Newburgh, and after visiting others in the same district, we cross the county in a south-easterly direction to Kilconquhar Loch, near Elie. Thence we travel westwards, following a zigzag route, by way of Clatto Reservoir, Carriston Reservoir, Loch Gelly, Burntisland Reservoir, Loch Fitty, and others, to the lochs situated on the Cleish and Lomond Hills, thence to Loch Leven, and finally to the Isle of May. The original paper contains forty-two illustrations of the lochs, etc., of this interesting area.

Lindores Loch is situated two miles south-east from Newburgh, amidst a beautifully wooded and agricultural country where hill and dale follow one another in quick succession. The loch is nearly a mile long and half a mile broad. Its water is not peaty, but is turbid and dead-looking. In many places there is deep, black, fetid mud, upon which submersed aquatics do not seem to flourish well. In several places, but particularly at the north-west and south-east ends, as well as on the east side, there are large associations of marsh plants. In other places there is a narrow strip of stony or sandy-muddy shore merging into meadow-land. Such shores are usually more or less overgrown with Juncus acutiflorus. This is particularly the case at the west side. Along a considerable portion of the east side runs the public road from Newburgh to Kirkcaldy. This is shut off from the loch by a wall which usually enters the water, and no marsh plants occur there. At other places on the east side there is a stony or sandy shore, similar to that on the west side, but usually with less vegetation. In the middle of the loch there is an island formed by a muddy flat, and densely overgrown with Phragmites communis. Many submersed plants have a deposit of lime upon their leaves and stems, and, as is commonly the case with lochs of this nature, filamentous Algæ, particularly Cladophora flavescens, abound. The striking features of the vegetation of this loch are the large quantities of the following plants:—Typha angustifolia, Glyceria aquatica, Scirpus lacustris, Phragmites communis, Phalaris arundinacea, Polygonum amphibium, Nymphæa lutea, Ranunculus circinatus, R. peltatus, and Myriophyllum alterniflorum, all of which occur in pure colonies over large areas of the loch, as well as mixed with other plants in some of the associations From the middle of the east shore a flat peninsula juts out into the loch. This is considerably overgrown with a number of the above-mentioned plants, particularly Typha angustifolia, as well as other species.

Black Loch is a small oval pool, surrounded by agricultural land, about a mile south-west of the last-mentioned. Excepting for a portion of the south shore, this loch is so entirely surrounded by marsh that the water cannot be approached. Its water is not peaty, but clear and bright, and is entirely encircled by a zone of Castalia speciosa and Nymphæa lutea, the latter being next the shore. At the south side no other plants occur between these and the gravelly-muddy shore, but elsewhere there is a zone of Equisetum limosum between the Nymphæa lutea and the land. Here and there all around the loch there are associations of Glyceria aquatica on the shore side of the Equisetum. In some places, particularly at the west end where there is a large bog, the Equisetum limosum is followed by Carex rostrata, and that in turn by Juncus effusus on the drier ground. Utricularia vulgaris abounds in the water.

Lochmill Loch is beautifully situated amongst the hills two miles south-west from Newburgh, which it supplies with water. It is about a quarter of a mile long, and half that in width. Low hills with grassy or cultivated sides surround it, excepting at the east end which is more open. There are plantations of coniferous and deciduous trees about the adjacent hillsides. Although peat occurs on the higher hills immediately to the south and west, it is doubtful if any appreciable quantity of peaty water gains access to the loch. There is not much marshy ground, although at the effluent at the east end, as well as here and there about the shore, small areas of marsh occur. Excepting for the marshy areas and a rocky part on the south-west, the shores consist of muddy gravel, and merge imperceptibly into the grassy banks. The water is clear, not peaty, and apparently of a steely grey colour, probably due to the copious deposit of black mud on the bottom, which arises from the rapid decomposition of a very luxuriant aquatic flora. Many of the submersed plants are heavily coated with a deposit of calcium carbonate, and others, particularly Littorella lacustris, are overgrown to an extraordinary degree with Diatomaceæ. On the north side there is a large association of Polygonum amphibium, which is frequently mixed with Potamogeton natans, and a belt of the latter extends along the outside of the Polygonum in deeper water. A similar phenomenon also occurs upon the south side. Potamogeton Zizii and P. lucens are both very abundant, and cover large areas of the bottom to a depth of 10 feet. Heleocharis acicularis not only occurs in the water to a depth of 3 feet, but also forms a sward upon the dry shore. A large number of other plants occur here, but Bryophytes, with the exception of a few ordinary marsh mosses, are scarce.

Kilconquhar Loch is about two miles north of Elie. It is a very shallow circular loch about half a mile across, and is so completely surrounded with marsh and reed swamp that the water can only be approached at a few places; consequently there is no definite shore. The village of Kilconquhar is situated on the north side of the loch, and the gardens from the adjacent cottages run down to its margin. The ornamental grounds of Elie House, which are wooded or park-like, adjoin and beautify the south side. Upon the east and west sides the loch is surrounded by agricultural land. The bottom of the loch at the north and west sides consists of deep black mud; but at the south and east sides the bottom is less muddy, and in many places is formed of firm sand. Near the shore the depth of water is from 3 to 5 feet, but towards the middle it is somewhat deeper, seldom, however, exceeding 7 feet. The water is clear, but has a stagnant appearance, which may be described as dead, in comparison with the sparkling water of a pellucid highland loch. In consequence of such favourable physical conditions, the whole of the bottom of this loch is more or less overgrown with plants. The marginal swamp vegetation is chiefly composed of associations of the following plants:—Scirpus lacustris, Equisetum limosum, Phragmites communis, Heleocharis palustris, Carex rostrata, Hippuris vulgaris, Typha latifolia, Epilobium hirsutum, Menyanthes trifoliata, Sparganium ramosum, and Phalaris arundinacea. The plant associations in the water are chiefly of the following species:—Polygonum amphibium, Potamogeton pusillus, P. filiformis, Zannichellia palustris, var. brachystemon, Myriophyllum spicatum, Callitriche autumnalis, Ranunculus circinatus, R. Baudotii, Chara aspera, etc. In many places large masses of Cladophora flavescens and Enteromorpha intestinalis were floating about at the surface. There are a few common bog mosses, but such are not abundant, as favourable situations are scarce. It should be mentioned that Polygonum amphibium and the two species of Ranunculus cover a large area of the loch, and when in flower present a unique spectacle.

Halton Reservoir is a small irregularly shaped sheet of water situated about two miles north of Largo. It has been formed by the widening of the natural gorge of the Halton Burn, and by the construction of a dam at the lower end. At the time of my visit the water had fallen about 12 feet below the full water-level, leaving upon the exposed mud the remains of a number of aquatic plants. Some of these were growing in terrestrial form upon the mud, *e.g.* Myriophyllum spicatum, Polygonum amphibium, Ranunculus peltatus, Potamogeton natans, Callitriche stagnalis, etc. Chara fragilis is extremely abundant, and Gnaphalium uliginosum forms a sward upon the sides near the full water-level. When the water is low this is not a very attractive place, because it has the appearance of a flooded quarry with a scanty vegetation upon its sides.

Clatto Reservoir is situated about three miles south of Springfield, in an upland district of which Clatto Hill is the highest point. It is a narrow sheet of water about three-quarters of a mile long, made by building a dam across the east end of the valley through which flows the Ceres Burn. The water is clear and not peaty, and is bordered in many places by a zone of marsh, or a narrow strip of stony shore may intervene between the water and the grassy banks. A plantation of coniferous trees skirts a portion of the south shore, otherwise the surrounding country is of the agricultural type.

At the south-east end an arm to the reservoir has been formed by constructing a dam across an adjacent valley and excavating a connection. At the west side of this arm there is a large marsh similar in its features to one at the west end of the main body of water. A considerable number of plants occur at this reservoir, but I did not notice anything of particular interest.

Carriston Reservoir is a circular sheet of water, a quarter of a mile across, situated two miles north-east of Markinch, in a rich agricultural district. It was formed by the construction of a long dam across a valley through which flowed a tributary of the river Leven. The water is clear and not peaty. The dam occupies most of the west side, and there is not much shore on the south, as a bank which is faced with stone-work frequently enters the water. On the north and east there is a flat sandy or muddy shore, and the small amount of marsh vegetation about this loch occurs there. On the north shore there is a mixed plantation and a few isolated trees; otherwise there are no trees in the immediate vicinity of the water. Heleocharis acicularis forms a dense sward on parts of the sandy-muddy shore to a greater extent than I have seen elsewhere; it also enters the water to a depth of 3 or 4 feet. On some parts of the exposed shore terrestrial forms of Myriophyllum spicatum were abundant, and in some places Gnaphalium uliginosum and Juncus bufonius formed a dense sward. Heleocharis palustris is abundant near the winter water-level, but the plants are dwarfed, probably because they are left comparatively dry in the summer, owing to the water receding from them. Ranunculus pseudo-reptans, resembling externally Ranunculus reptans, is much more abundant here than at any part of the shores of Loch Leven. Bryophytes are scarce, and the other vegetation is somewhat restricted in species.

Kinghorn Loch is a small rectangular sheet of water close to Kinghorn. The water is not peaty, but is turbid and dead-looking. The west shore, which is flat and muddy, merges gradually into meadow-land, and this is the only part where there is any abundance of marsh vegetation. The east shore is stony and rocky, a considerable portion of it consisting of bare volcanic rock. Upon the north and south sides there is scarcely any shore. The most interesting feature noticed at this loch was the vast quantity of Anabæna Flos-aquæ, var. circinalis. In many places this alga was so abundant, on 27th May 1905, that the water resembled pale green paint. Polygonum amphibium is very abundant on the west side of the loch, and a limited number of other plants were also observed.

Loch Camilla is a small oval sheet of water about four miles east of Cowdenbeath. The water, which is not peaty, is rather turbid, and is surrounded by agricultural land. The shores on the east are stony, and bear but few plants, but at the west end there is a considerable development of marsh vegetation. A large association of Equisetum limosum, mixed here and there with patches of Hippuris vulgaris, stands out in the water. Nearer the land there is a large area of Carex rostrata, behind which a wide stretch of bog, that gradually merges into meadow-land, is covered with a variety of plants. Ranunculus hederaceus, in both terrestrial and aquatic forms, occurs here. There are also similar forms of R. peltatus, and a curious terrestrial form of the latter having purple blotches on the peltate leaves suggestive of a crossing with R. hederaceus. A number of Bryophytes are abundant at this marsh, and amongst them Marchantia polymorpha in aquatic form.

Loch Gelly is an oval loch, about three-quarters of a mile long situated two miles east of Cowdenbeath, and close to the village of Lochgelly. The loch is surrounded by low hills, except on the west side, where the country is quite open as far as Cowdenbeath. The district around is of the agricultural type, with a few acres of rough, boggy pasture at the west end of the loch, which was probably a portion of its bottom at a former period. The margins of this shallow loch are so gently inclined that only in a few places can a boat be brought within 20 feet of the shore. The surrounding land at the north and east slopes gently towards the water, and is covered with a fine, close grass sward, about which there are a few large deciduous trees. This meadow-land gives place near the water's edge to a narrow shore of dirty sand or gravel, with a few larger stones; but except for a few sparse patches of Littorella lacustris, etc., there is no vegetation on these shores. The west shore consists chiefly of a Phragmites swamp, behind which there is a considerable area of boggy pasture, as previously mentioned. At the north-west corner, however, the bog is occupied by species of Carex, etc. The south shore has a zone of marsh throughout its length, immediately behind which there is a narrow plantation of conifers, mixed here and there, on the damper spots, with alders, poplars, willows, etc. For several years this loch was used as the common receptacle for the sewage of the populous mining district around. The inflowing burn at the west end was then an evil-smelling open sewer 6 or 8 feet wide; consequently the water of the loch was extremely foul. The local sanitary authorities, however, became enlightened regarding the danger of this mode of sewage disposal, and forthwith adopted a more modern method. Meanwhile certain colliery owners found in the affluent a convenient means of disposing of their mine water, as well as the waste from coal-washing machinery, so that now the burn resembles a stream of ink, and the loch is being silted up with a deposit of coal dust. The influence of such filthy additions is seen over the whole of the loch, particularly at the west end, where the deep, black mud has an insufferable odour. When the loch received the sewage, the water had a turbid, unwholesome appearance, and was everywhere crowded with plankton organisms, besides which all objects about the shores were covered with filamentous Algæ, chiefly Cladophora fracta, whilst there were innumerable floating masses of Enteromorpha intestinalis and Cladophora flavescens. Now the water is black and dead-looking, and the Algæ have considerably diminished, especially the Cladophoræ, whilst everything is covered with black filth. The marginal vegetation previously mentioned is luxuriant, although somewhat restricted in variety, but the submersed plants are scarce, which is not surprising when one considers the vicissitudes through which the loch has passed.

Standing out of shallow water there are pure groups of Iris Pseudacorus 5 feet high, and the same occurs at Loch Fitty. Some very large clumps of Cardamine pratensis were also found here. Many of these were propagating vegetatively by the production of plantlets from buds at the base of the leaflets. Near the boat-house on the north-west shore there is a great bed of Potamogeton pectinatus. A curious submersed form of Alisma Plantago growing in 18 inches of water, with delicate linear-lanceolate leaves floating on the surface and linear submersed ones, was abundant. A number of other plants found at this loch are listed in the original paper.

Burntisland Reservoir is an irregularly shaped sheet of water, situated amidst picturesque surroundings two miles north of Aberdour, and lying between the hills of Dunearn, Balcam, and Cullalo. It was formed by the construction of a short dam at the south-west end. Upon the south side the loose rock and soil have been protected by stone-work, which in most places enters the water. Excepting a few lichens and Bryophytes, no vegetation occurs either along this wall or at the dam, but at all other parts of the margin vegetation is abundant. The shores, where bare of plants, are either gravelly or muddy, and the water, which is not peaty, has a slightly turbid appearance, due to the somewhat impure water of one of the affluents and to the erosion of the muddy shore by the waves. These matters, however, are about to receive attention from the authorities at Burntisland, who own the reservoir, and the proposed alterations will, I fear, eradicate a number of interesting plants from this locality. About the affluent at the east end there is a considerable extent of marsh, which, near the water, is covered with Equisetum limosum and Heleocharis palustris. From this place to about the middle of the loch, where there is a large bay, the flat shore, which is usually exposed in the summer by the falling of the water-level, is sandy or muddy and is covered with vegetation. Littorella lacustris grows out of the water and for some distance up the shore. Then there is a broad zone of Heleocharis palustris, with which a few other species of plants are mixed. Above that a narrow strip of Spiræa Ulmaria grows at the winter water-level, where the storms deposit a supply of rich detrital matter, and behind this there is a luxuriant grass meadow. Similar conditions also prevail along the east side of the bay already mentioned. The wide zone of Heleocharis is cut every summer, and dried for use as bedding for cattle, but chiefly in order to prevent the dead stems being washed into the loch during winter, as the decay of so large a quantity of vegetable detritus would pollute the water. A large number of plants grow at this reservoir, for which the original paper may be consulted. Amongst others the following plants, of less common occurrence at lochs, were found here :—Interesting terrestrial forms of Littorella lacustris, an aquatic form of Bryum pallens, Riccia crystallina, Potamogeton obtusifolius, var. fluitans, Myriophyllum spicatum and M. alterniflorum growing together, Juncus glaucus, Veronica scutellata, etc.

Otterston Loch is a small sheet of water two miles west of Aberdour. It is closed in by low hills, and is entirely surrounded by luxuriant deciduous trees, which also cover a small island in the middle. The water is not peaty and, although clear, it has a dead, stagnant appearance. The loch is of an ornamental nature, and Otterston House stands upon its north side, whilst the public road borders it on the north-east. Except on the west side, where there is an extensive and treacherous bog, the loch is bordered nearly everywhere by low walls or grassy banks, so that there is practically no shore, but in several places marsh vegetation overgrows the banks. At the west end the mud at the bottom is deep, black, and fetid; there is much less mud at the east end, where some parts of the margin are sandy, or a narrow zone of stones may even occur. Ceratophyllum demersum is so abundant that the loch is almost choked with it, and in the summer when the plants are at the surface, the manipulation of a boat over the water is a matter of some difficulty. Doubtless many plants that otherwise would thrive in this loch are excluded by the Ceratophyllum. It does not, however, appear to be able to hold its own in the marginal zone against a large association of Polygonum amphibium which grows there. Considerable portions of the bog at the west end are covered with associations of Menyanthes trifoliata, Ranunculus Lingua, and Carex paniculata. The last-mentioned grows in large tussocks, and dominates the greater portion of the bog. A considerable number of other plants grow at this loch, the most uncommon species being:—Zannichellia palustris, Lemna trisulca, Cicuta virosa, and Scirpus sylvatica near the loch (Pl. I. and II.).

Loch Fitty is situated amidst a mining and agricultural district, three miles west of Cowdenbeath. It is a mile long by one-third of a mile wide. The water is clear, but it has a flat, dead appearance, especially so in autumn when the vegetation, particularly Chara, is decomposing. The shore at the north side is stony or gravelly, and almost destitute of marsh plants. At the south side a portion of the shore is composed of shale, which has been thrown out from an adjacent mine, and a number of aquatic plants occur in the pools and little bays formed by the irregularities of this substance. At other places upon this side of the loch the shore is gravelly or sandy, and bears more plants than is the case upon the opposite side. At the west end the affluent enters the loch, previous to which it has a very sinuous course for about a mile through an alluvial flat consisting of agricultural or meadow-land, doubtless at one time covered by the water of the loch.

Near the loch this flat merges gradually into a bog several acres in extent. At the east end there is a similar but much less extensive bog. The loch is shallow throughout its area, a depth of 10 feet being seldom exceeded, and a considerable portion of the bottom is covered with Chara fragilis and its var. delicatula, besides a large number of other plants. The stones about the shores are everywhere thickly covered with Cladophora canalicularis and C. flavescens, both of which bear an extraordinary quantity of Diatomaceæ, chiefly of the genera Diatoma, Gomphonema, and Cocconeis. A fine tow-net used in the middle of the loch at the end of September caught a very pure collection of Asterionella formosa. Many of the submersed plants were incrusted with lime, which proves the presence of that substance in the water. Here and there are pure groups of Iris Pseud-acorus, with leaves 4 or 5 feet high, standing out of the water as little islands. Nine species of Potamogeton and one variety flourish in this loch, most of them in abundance, and, besides a large number of common plants, the following which are of less frequent occurrence were observed:—Anacharis Alsinastrum, Sparganium longissimum, Carex aquatilis, Juncus glaucus, Veronica scutellata, and Hypnum stramineum. Scirpus lacustris and Phragmites communis grow here, but, strange to say, both are quite dwarfed compared with their usual luxuriance in similar lowland lakes.

Town Loch, which is only a few hundred yards long, is about two miles north of Dunfermline, and close to the mining village of Townhill. At the time of my visit the water had fallen several feet owing to dry weather, and a large expanse of uninviting shore, composed of sandy gravel, mud, and coal dust, was exposed. At the full water-level there is a zone of vegetation composed chiefly of plants of the damp meadow type, with which are mixed some of those species usually associated with the shores of a loch. The water is extremely foul, as the loch is used as a receptacle for sewage. Three plants dominate the water, namely, Chara fragilis, Potamogeton flabellatus, and Polygonum amphibium. The Chara was the type form of fragilis, and in a very prolific condition.

Loch Glow is situated in an open position on the Cleish Hills. These hills are for the most part covered with a grass-like formation of plants, below which there is peat. The loch is the largest of a series of four; it is three-quarters of a mile long by half a mile broad, and is 900 feet above sea-level. The original loch has been deepened by the construction of a short dam at the east end, and it is now used as a reservoir. The water is clear, but slightly peaty. The north shore is rocky, stony, or more rarely sandy, and the south shore is mostly peaty. Bearing in mind its wind-exposed position, and the unsuitable nature of the shores, it is not surprising that semi-aquatic plants are practically absent. A few leaves of Littorella lacustris, that had been cast upon the shore, were the only evidence of submersed aquatic plants that I could discover without the aid of the boat, which at the time of my visit was out of repair. Possibly there are plants upon its bottom, but so far as I could find, this loch is devoid of botanical interest.

Black Loch is a small sheet of water about a mile west of Loch Glow, and is surrounded by hills. The water is somewhat peaty, and there is scarcely any shore, save a few stony places here and there, as the grassy moor terminates in a bank at the water's edge. There is a thin association of Phragmites communis stretching along the south shore. Carex rostrata and Equisetum limosum occur in patches about the margin, Nymphæa intermedia grows at the west end, whilst Potamogeton rufescens, var. spathulifolius, grows there, and at other parts of the loch as well, in great abundance. A number of common plants were also noticed at this loch.

Loch Dow is a small oval sheet of water, situated in a hollow of the grassy moor, half a mile north-east of Loch Glow. The water is slightly peaty, and the stony or rocky shores on the north and east are narrow, with a sparse vegetation, or the moor meets the water without the intervention of a shore. Extending around the south and west sides there is an extensive bog, mostly occupied by Carex rostrata, which advances into the water on the one hand and merges into the grass formations of the moor on the other hand. A number of other common plants occur here.

Loch Larg is a few hundreds of yards north of the last-mentioned, and is very similar to it, excepting that its eastern shore is more stony. There is a flat, boggy area along the west side, which is covered, near the water, with Carex rostrata. Adjoining the moor this bog is overgrown with Calluna vulgaris, Polytrichum commune, P. gracile, Sphagnum cymbifolium, S. intermedium, etc. A slight but sudden rise of the ground causes an abrupt termination to the vegetation just mentioned, and in its place associations of grass-like plants, amongst which Scirpus cæspitosus is dominant, extend towards the moor. The line of demarcation between the Calluna and the grass-like formations is quite sharp, and probably marks the original extent of the loch. A number of plants commonly found at hill lochs occur here, including several Bryophytes which flourish at the two foregoing lochs as well.

Harperleas Reservoir is situated on the Lomond Hills, at an elevation of 848 feet above sea-level. It is about half a mile long, and is of an irregular shape, with clear but somewhat peaty water. It has been formed by the construction of a long dam at the east end. The south shore is either stony or muddy, and at some places the bank enters the water without the intervention of a shore. At the north and west the shore is flat, and muddy or peaty, and is covered with a luxuriant vegetation, whilst there is very little at the south shore, and none along the dam. A zone of Equisetum limosum extends along the greater part of the north side, intermingled with Littorella lacustris, which runs up the shore and forms a dense sward in some places. Occasionally considerable areas of exposed mud were covered with Juncus fluitans, which was reverting to the terrestrial type, J. supinus, which it somewhat resembled. Other normally submersed plants were assuming a terrestrial habit and forming a meadow-like sward upon the exposed shore, particularly Ranunculus aquatilis, Heleocharis acicularis, Polygonum amphibium, Potamogeton polygonifolius, and P. heterophyllus. The normal aquatic form of the last-mentioned was very abundant at this loch. Those left upon the exposed mud were developing new aerial leaves, similar to the coriaceous floating ones, but smaller, the thin submersed leaves having completely withered away. At the north-west end a portion of the shore presented a remarkable appearance, through being covered with dead tussocks of Molinia cærulea, which had been drowned during some period when the water-level was abnormally high.

A little to the east of Harperleas is Ballo Reservoir, both being situated on an upland plateau which forms the south flank of the East and West Lomond Hills. These reservoirs are surrounded by moor of the grass or heather type, or a superior pasture-land which is due to cultivation. Harperleas Reservoir is treeless, but Ballo has a plantation of conifers upon its south-west shore. There are also a few plantations in the neighbourhood of the reservoirs, which pleasantly relieve the sameness of the moor and add a picturesque charm to this pleasant, although small, stretch of upland country.

Ballo Reservoir has a somewhat pear-shaped outline, with the narrow end towards the south-east. It is about a mile long by half a mile wide at the broadest part. In general features it much resembles Harperleas Reservoir, but there is less variety in the species of plants. At the north-west end there is an extensive peaty-muddy flat, covered with an association of Juncus effusus. This flat area extends out into the loch for some distance, and, in the dry season, is exposed by the falling of the water. It is covered with Littorella lacustris, Heleocharis acicularis, and Juncus fluitans, all of which assume the terrestrial habit when the water has receded. At the same end of the loch, but nearer the north side, Hydrocotyle vulgaris extends over a considerable area and forms a dense sward. Equisetum limosum forms a zone along a portion of the north shore, as at Harperleas Reservoir, behind which there is a strip of boggy ground covered with Carex, etc., and at one place there is an association of Typha latifolia. The shore along the north and east is flat and peaty, and a wide strip of it, exposed by the falling of the water, was more or less covered with Juncus fluitans which was reverting towards the terrestrial type. A number of species were observed at these reservoirs besides the above-mentioned, amongst them the following which are not very common in Area VII.:—Fontinalis antipyretica, Callitriche hamulata, Peplis Portula, Veronica scutellata, and Ranunculus pseudo-reptans.

Loch Leven is situated in the lowest part of a somewhat oval strath, which is bounded by the Cleish Hills, Benarty Hill, the Lomond Hills, and the Ochil Hills. It is somewhat pear-shaped in outline, with the apex lying to the south-east. It is $3\frac{2}{3}$ miles long by $2\frac{2}{3}$ miles wide at the broadest part. The surface of the loch is 350 feet above sea-level, and as the land for some distance around is below the 400-feet level, it must, at a former period, have been very much larger. It was artificially reduced in size in 1845, when its level was lowered $4\frac{1}{2}$ feet. On account of the shallow marginal zone this slight lowering of the level reduced the area by about 1400 acres. For its size it is an extremely shallow loch, the greater portion of it being less than 15 feet deep. Indeed, along the east shore an area nearly three miles long by nearly a mile broad is mostly less than 9 feet deep. It has, however, two depressions, each having a depth of about 80 feet—one to the west of St Serf's Island, and the other to the north-east of Scart Island. If the effluent were lowered 22 feet, so as to reduce the level of the loch by that amount, about 3000 acres of land would be reclaimed. There are six islands in the loch. The largest of them, called St Serf's Island, has an area of about 80 acres; it is quite treeless, and is utilised as a rabbit-warren. Castle Island is covered with trees, and has an extent of about 5 acres. The other islands are quite small. The shores are everywhere flat and usually sandy, particularly on the east side, where the sand is sometimes blown into small dunes. More rarely the shore is composed of stones, or there is no shore because meadow-land comes down to the water's edge. In a few places there is a narrow zone of marsh extending a considerable distance along the shore, as, for example, upon both the east and south sides opposite St Serf's Island. In many places there are large quantities of vegetable remains, chiefly those of Chara and Anacharis, lying upon the shore at the winter water-level. The flat shores of this loch are in many places very much exposed to wind, and due to this influence is the fact that some plants, which ordinarily grow erect, here assume a prostrate habit; such, for example, as Equisetum arvense, Juncus bufonius, J. acutiflorus, J. supinus, Ranunculus Flammula, etc. There are two or three associations of Phragmites communis, as well as of Heleocharis palustris and Equisetum limosum, that enter the water here and there; otherwise there are no plants of the semi-aquatic type in the water of the loch. The water is fairly clear, and not appreciably peaty. The bottom of the loch, from the shore to a depth of about 15 feet, consists largely of firm sand, which is, however, frequently dirty and mixed with mud. Where the bottom is of this nature it is usually carpeted with Chara aspera, or its var. subinermis, to a depth of 14 or 15 feet. The growth of these plants at a depth of from 4 to 8 feet is prodigious, but they thin out towards the shallower water on the one hand, and towards the deeper water on the other. Nitella opaca occupies considerable areas, also where the bottom is sandy, and at similar depths to the Chara, but it has a tendency to be most abundant in slightly deeper water than that in which the maximum growth of the Chara occurs. On the few areas where the bottom, from near the margin to a depth of 15 feet, is of mud—for example, at the west side of the loch and in the bay at the east end of St Serf's Island—Anacharis Alsinastrum grows with such extraordinary vigour that in the summer, when these plants are near the surface, it is very difficult to row a boat through them. At greater depths than about 16 feet no living vegetation of the higher type occurs, and mud covers the bottom nearly everywhere. This mud, which is usually blackish with a somewhat offensive odour, was in August crowded with worm-like larvæ at many parts of the loch. Among a number of other plants which grow in the water the most abundant is probably Potamogeton perfoliatus. The boat-keeper at the loch informed me that, previous to the extensive development of the Anacharis, this Potamogeton was extremely abundant, and that it had been partially exterminated by the former plant. A considerable number of plants grow at this loch, amongst which the following are not of frequent occurrence in Area VII.:—Carex aquatilis, C. hirta, which grows on the sandy shores like C. arenaria on the sea-shore, Alisma ranunculoides, Lysimachia nummularia, and Ranunculus reptans. A few Bryophytes occur in marshy places, but are not abundant, excepting on parts of the south shore.

The Isle of May is situated at the entrance to the Firth of Forth, and I was induced to visit this isolated spot in order to investigate a small loch which is there, thinking it might afford something of interest because of the numerous water-birds that visit the island during their migrations. The loch, which is quite small, is situated in a ravine that divides the island obliquely in the direction S.E. by E. and N.W. by W. From the rocky and precipitous nature of the ravine one might imagine the pool to be a little lochan high on the mountains. The extensive engine-house at the east end, and the cement dams at both the east and west ends, however, quickly dispel such a pleasant illusion. The water, which is maintained at a depth of about 7 feet by the dams, is used for the engines that generate the electricity for the lighthouse and the compressed air for the fog-horn. No aquatic phanerogams or higher cryptogams exist either in the water or about the shores of the loch, but the water is coloured yellowish-green by the abundance of minute Myxophyceæ, Bacteria, Infusoria, and Entomostraca, and by the waste water from the adjacent engine-house. The water is so discoloured that the bottom can only be seen at a depth of a few inches, and the engineer informed me that the discoloration is maintained throughout the year. It must not be imagined, however, that the cliffs about the loch are bare of vegetation, for besides grassy slopes and banks, the rocks and crannies are clothed with a variety of plants such as are common to the maritime cliffs of the adjacent mainland. An account of the terrestrial plants is given in the original publication.

In conclusion, I desire to express my obligation to Sir John Murray and Mr Laurence Pullar for the assistance they have at all times freely given me, without which these pages could never have been written. I should like also to thank Mr James Chumley for his generous help, so freely given on many occasions.

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PART IV.—THE PLATES

Plate I.—An example of a typical lowland loch. A general view of Otterston Loch, from the N.E. corner, looking S.W. The loch is surrounded by luxuriant deciduous trees, and the small island is covered with a similar growth. The shores are overgrown with vegetation, and the surface of the water is to a considerable extent covered with aquatic plants (*vide* p. 254 and Plate II.).

George West.

OTTERSTON LOCH, FIFE

PLATE II.—An example of a typical lowland loch. Otterston Loch from the N.E. corner, but from a position more to the west than the spot from where Plate I. was taken, looking W. and showing a portion of the N. side, adjoining which is the public road from Aberdour. The surface of the water in the foreground is covered with Polygonum amphibium (*vide* p. 254 and Plate I.).

George West.

OTTERSTON LOCH, FIFE.

PLATE III.—An example of a typical exposed highland loch. A general view of Lochan Creag Madaidh from the S. end looking N.N.E. The mountain in the background is Beinn Dearg, behind which, on the right, appears the top of Meall Crumach; Glen Lyon lies between the loch and Beinn Dearg. The surrounding moor is a mixture of heather and grass. The shores of the loch are rocky, treeless, and, excepting for the small associations of Carex in the bays on the west side, bare of vegetation; neither are there any aquatic plants floating on the surface (*vide* p. 167 and Plate IV.).

George West.

Lochan Creag Madaidh, Perthshire.

Plate IV.—An example of a highland loch that is apparently sheltered, but which in reality is exposed to terrific gusts of wind that descend from the adjacent mountains. A view looking across the eastern portion of Lochan a' Chait from its S. shore northwards. The western and larger portion of the loch is to the left, a part of it only being shown in this picture. The mountain rising precipitously at the north side almost from the water's edge, is Meall Garbh (3661 feet). From the S. side of the loch Ben Lawers rises, but not so precipitously, to a height of 3984 feet. The general features of the vegetation of the loch are similar to those described for Plate III.

George West.

LOCHAN A' CHAIT AND MEALL GARBH, PERTHSHIRE.

Plate V.—An example of a loch lying in a large and deep main glacial trough with numerous lateral valleys. A general view of Loch Ness and Fort Augustus from the hill immediately to the west of Cullachy House, looking N.E. The strath below consists of moor, plantation, and cultivated ground. The lower slopes of the mountains adjoining the loch on either side are in some places cultivated, but are mostly occupied by either forest or moorland vegetation (*vide* p. 197 and Plate VI.).

George West.

LOCH NESS, INVERNESS-SHIRE.

Plate VI.—An example of waves breaking upon the gravelly shore of a loch. Loch Ness from near the embouchure of the river Tarff, looking up the loch in an N.E. direction, and showing some of the features described for Plate V. The mountain in the centre of the picture is Beinn a' Bhacaidh, and the vessel is the L.S.Y. *Suzan* at her station on the loch (*vide* pp. 167 and 198).

George West.

LOCH NESS, INVERNESS-SHIRE.

PLATE VII.--An example of a loch that is being reduced in size by the formation of a strath, due to detrital sand and gravel brought down by a river. View from the S. shore of Loch Killin, near the embouchure of the river Killin (which appears on the left), looking up the strath towards Sronlairig. The gravelly shore of the loch, in the foreground, is being encroached upon by tussocks of Juncus effusus and other plants. The Juncus is the vanguard from a large association farther up the strath. The encroachment of the strath upon the loch is said to be at the rate of about 6 inches per annum (*vide* p. 210 and Plate VIII.).

George West.

VIEW FROM THE SHORE OF LOCH KILLIN, INVERNESS-SHIRE.

PLATE VIII.—A view of the same subject as Plate VII., but farther up the strath where the ground is drier. Between the colonies of Juncus effusus, which are here beginning to thin out, grass-like associations occur, and these afford pasturage for sheep. Farther up still the Juncus almost disappears, and there good grazing ground may be found.

George West.

VIEW FROM THE SHORE OF LOCH KILLIN, INVERNESS-SHIRE.

Plate IX.—An example to show that the area of cultivation by the steep sides of the larger highland lochs is restricted to the lower slopes of the mountains. A view across Loch Tay from Kepranich looking N.W. The two crofts—Wester and Easter Cloanlawers—are seen on the opposite side of the loch, which is here two-thirds of a mile wide. The small area of cultivation is easily distinguished by the dykes which enclose the fields; the lighter patches near the houses are oat-fields. The lower hill on the left with a few coniferous trees is Creag Dhubh, behind which appears Ben Lawers, the mountain on the right being Meall Garbh. The trees on Creag Dhubh were mostly blown down by the great storm of November 1893, those seen in this picture being the survivors (*vide* p. 161 and Plate IV.).

George West.

VIEW ACROSS LOCH TAY, PERTHSHIRE

THE DEPOSITS OF THE SCOTTISH FRESH-WATER LOCHS

By W. A. CASPARI, B.Sc., Ph.D., F.I.C.
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In the course of the survey of the fresh-water lochs of Scotland some seven hundred samples of bottom-deposits were brought up, and eventually sent to the *Challenger* Office at Edinburgh. No systematic plan was adopted in collecting the deposits, and therefore some lochs are represented by a large series of samples, others by only a few, and others again (small lochs and reservoirs) by none at all. To some extent this is due to the practical difficulties of sampling, in that the sounding-tube frequently came up empty, or the material slipped out before it could be secured. Nevertheless, the material at hand is both plentiful and interesting. It has now, therefore, at the suggestion of Sir John Murray, been submitted to laboratory examination.

With a few exceptions, the Scottish lochs have deposits which differ scarcely at all from loch to loch. The great majority of the mainland lochs exist under closely similar conditions: they lie in a country of fairly uniform mineralogical aspect, are provided with an inflow and an outflow of soft peaty water, receive a large supply of vegetable refuse, and are remote from thickly populated districts. Consequently the floors of the various lochs tend to be carpeted with much the same kind of deposit, and it is possible to deal generally with the deposits as if they belonged to one huge lake. Only in certain island lochs on the one hand, and in small and comparatively stagnant lochs on the other, are local peculiarities developed, which will be referred to in due course.

Scottish loch deposits in general may be classified into three main varieties, viz. :—

(1) Sand or Grit.
(2) Clay.
(3) Brown Mud.

Three other types of deposit occur sporadically and are by way of being rarities, viz. :—

(4) Diatom Ooze.
(5) Ochreous Mud.
(6) Calcareous Deposits.

1. Sands, etc.

Wherever the bottom of a loch lies under briskly moving water, as within the sphere of wave-action or at the inflow of a rapid river, the deposits are graded by elutriation, and the finer material is carried away. The residue will consist of coarse and heavy mineral grains comparable to sea-sand. Sandy loch deposits, then, are only found in shallow depths, and usually near the shore-line. They consist chiefly of quartz, felspar, and mica, and are free, or nearly so, from clayey matter; the more vigorous the elutriating agency, the more does quartz tend to predominate. Sandy deposits are often discoloured by organic matter, which is apparently not washed away so easily as clay; also by limonite, existing as a tenacious incrustation on quartz grains. An analysis of a sand from Loch Ness, 30 feet, has been published in an earlier paper of the Survey.[1] In the majority of Scottish lochs, which are more or less steep-sided and U-shaped in section, the layer of sandy deposit may be supposed to extend from bank to bank, underlying deposits of finer material in the inner part of the loch, and being itself underlain by yet coarser grains and pebbles. This scheme of stratification was well illustrated by some of the Survey soundings, in the rare cases when it was possible to bring up a long plug in the sounding-tube. As regards the origin of sandy deposits, it is clear, since they are too coarse to be transported to any extent by water, that they are derived from the rocks immediately surrounding the loch. They are, as it were, autochthonous, and differ in this respect from the material of the finer mineral deposits (Clays), which may in part have arrived from great distances.

2. Clays

The term Clay is here applied to any mineral deposit which is sufficiently fine-grained and coherent to have a certain plasticity in the wet state. In the Scottish lochs Clays and Brown Muds shade off into one another through an infinity of gradations; we may regard as typical Clays those specimens (and they are plentiful enough) which contain practically no organic matter, and are farthest removed from the Brown Mud end of the series. Such

[1] *Geogr. Journ.*, vol. xxxi. p. 60, 1908.

lacustrine Clay is of a very light greyish or yellowish tint, and is much paler than any submarine inorganic deposit. It consists chiefly of finely divided quartz and mica, with minor proportions of felspathic, chloritic, and ferro-magnesian minerals.[1] There is always present a certain amount of clay proper, *i.e.* amorphous hydrated alumino-ferric silicate, which imparts to the deposit its plastic character; but the amount is often very small, and always much smaller than in oceanic Clays.

Without resorting to an exhaustive analysis, an indication of the proportion of true clay in these deposits may be gained from their ignition losses. Organic matter being absent, ignition loss will represent the water of hydration of the clay present *plus* that of the mica present. Five samples of pale Clay, which gave little or no coloration with caustic soda solution, and were therefore regarded as free, or nearly so, from organic matter, were thus assayed; they were weighed out after drying at 110° C.

Deposit.	Loss at Low Red Heat.	Total Loss over Blast.
Loch Assynt, 83 feet . .	...	3·93 per cent.
,, Ness, 95 ,, . .	...	1·95 ,,
,, Laggan, 59 ,, . .	...	3·48 ,,
,, Earn, 61 ,, . .	3·30 per cent.	4·24 ,,
,, Maree, 56 ,, . .	2·96 ,,	3·44 ,,

Since ideal clay ($Al_2O_3.2SiO_2.2H_2O$) would give off over 14 per cent. of water on ignition, these figures speak for themselves. A rough attempt at discriminating between water of clay and water of mica was made on the last two samples, by igniting first at low red heat and then over the blast. If it were desired, the method might be made one of considerable accuracy by careful temperature adjustment, direct weighing of the disengaged water, and addition of sodium carbonate or lead peroxide in the final ignition. As it is, the Loch Earn sample shows about 23 per cent. of clay and 20 per cent. of mica, the Loch Maree sample about 21 per cent. and 11 per cent. respectively.

Clays are met with in all the larger lochs. The absolute depths at which they occur are of course very variable; but generally speaking they are characteristic of relatively shallow water, and they are never found, except as thick under-layers, at the bottom of deep basins. They constitute the natural silt or alluvium of lochs, composed of the geological detritus of the surrounding country. Clays may be introduced directly by erosion of the banks or indirectly

[1] For analyses of Clays and determinations of minerals see *loc. cit.*

from affluent rivers; they form the substratum of all lacustrine deposits, and it depends largely on hydrodynamical conditions whether they shall remain exposed or become covered with another kind of deposit. Wherever the water is in gentle motion, sufficient to wash away organic debris but not vigorous enough to produce sands, there will be a surface deposit of Clay. The sedimentation of Clay is continually proceeding all over a loch (except at parts of the shore-line), but most rapidly at the embouchures of affluents. On comparing lacustrine with oceanic Clays one is struck by the comparative paucity of argillaceous matter in the former; this is due partly to the greater age of the ocean, in which the chemical degradation of silicates has been able to progress further than in lakes, and partly to the tendency of true Clay to remain suspended in fresh, as distinct from salt, water, and to be carried out to sea. Again, the Clays of the Scottish lochs are conspicuously less ferruginous than those of the deep sea, which is doubtless due to the marked solvent power on iron compounds of peaty waters. Although much of the iron thus extracted returns to the loch deposits in organic combination (Brown Mud), the greater part is probably lost irrevocably to the mainland and eventuates at the bottom of the sea.[1]

3. Brown Muds

Brown Mud is the Scottish loch deposit *par excellence.* Its characteristic constituent is an impalpable brown humus-like product of the decay of vegetable matter. This substance usually shows no coarse remnants of tissue and is quite amorphous, though often coagulated into tiny balls. It is found occurring mingled in all proportions with the other kinds of loch deposits. Brown Muds, even the most typical, are never purely organic, but are invariably mixtures of vegetable and mineral detritus. The organic component contains iron (and a little manganese) in combination, and when wet Brown Muds are preserved in bottles iron is often found to be leached out, and to form a scarlet limonitic scum at the upper surface in contact with air.

As to the chemical nature of the organic component of Brown Mud little can be said, in view of our scanty knowledge of the chemistry of humus. It is separable into two distinct portions. The one, which may be referred to as alkali-humus, dissolves readily in dilute alkalies or ammonia, giving a deep brown solution. From this solution acids bring down a dark brown flocculent substance which is very sparingly soluble in water or alcohol, dissolves partially in glacial acetic acid, and contains iron. A specimen of alkali-humus

[1] *Cf.* Murray and Irvine, *Proc. Roy. Soc. Edin.*, vol. xviii. p. 240 (footnote), 1891.

(*a*) derived from a mixture of Brown Muds, and another (*b*) from a Loch Lurgain mud, 146 feet, were examined quantitatively, after drying at 110° C. They contained:—

		(*a*)	(*b*)
On total substance, iron as Fe_2O_3 . .		7·9 per cent.	6·1 per cent.
On non-mineral portion only	Carbon	51·8 ,,	53·4 ,,
	Hydrogen	5·0 ,,	4·6 ,,

Alkali-humus is not free from nitrogen, but to determine in what form and amount this element is present more material would be needed than was at disposal. The organic matter not dissolved by alkali is a light yellowish-grey, not markedly ferruginous powder, which evidently consists of disaggregated but not fully decomposed vegetable tissue; under the microscope it appears as a mass of amorphous fragments with a few cells and shreds of fibre interspersed.

Some idea of the quantity of organic matter in Brown Muds and other loch deposits may be gained from the subjoined determinations of carbon. Six deposits were taken, namely:—

(1) Loch Lurgain, 59 feet, a slightly sulphuretted Brown Mud.

(2) Loch Frisa (Mull), 175 feet, a dark-coloured Diatom Ooze.

(3) Loch Veyatie, 95 feet, a typical Brown Mud.

(4) Loch Rannoch, 323 feet, a Brown Mud in an incipient stage of passing into Ochreous Mud.

(5) Loch Gainmheich, 22 feet, a stiff brown Clay.

(6) Loch Assynt, 23 feet, a typical Ochreous Mud.

Of Nos. 1–5 the fine washings were separated (coarse minerals insignificant except in No. 4, 20 per cent., and No. 5, 52 per cent.); No. 6 was dealt with as a whole; the materials were dried at 110° C. Ignition losses were determined on one portion of each sample, and combustion analyses were carried out on another, with the following results:—

No.	Ignition Loss.	By Combustion.			Organic Matter.
		Carbon.	Water.	Loss.	
1	27·68 per cent.	11·95 per cent.	14·76 per cent.	26·01 per cent.	23·9 per cent.
2	18·27 ,,	6·09 ,,	13·51 ,,	16·84 ,,	12·2 ,,
3	37·08 ,,	18·28 ,,	19·87 ,,	35·73 ,,	36·5 ,,
4	24·24 ,,	11·60 ,,	13·59 ,,	23·06 ,,	23·2 ,,
5	9·86 ,,	2·82 ,,	6·19 ,,	8·43 ,,	5·6 ,,
6	12·68 ,,	1·26 ,,	10·11 ,,	11·34 ,,	2·5 ,,

The carbon in the vegetable matter associated with Brown Muds amounts roughly to 50 per cent.; hence the figures in the last column, obtained by multiplying the carbon percentages by two, represent approximately the proportion of organic matter present, and afford a measure of the simultaneous deposition of humus and mineral silt. It will be seen that even the richest Brown Mud (No. 3) still contains fine minerals to the extent of about two-thirds. The discrepancy between the ignition-losses in the first column (over the blowpipe) and those in the fourth (at dull red heat) is due to the water of constitution of the micaceous residue. From the high ratio of water to carbon in Nos. 1 and 5 the presence of notable admixtures of argillaceous matter may be inferred; the same disproportion in No. 2 is accounted for by diatomaceous silica, and in No. 6 by limonite.

The ignition-residue, representing mainly mineral silt, of the Brown Mud No. 3 showed on analysis:—

SiO	56·62
Al_2O_3	21·59
Fe_2O_3	13·43
MnO	0·94
CaO	1·47
MgO	1·28
K_2O	4·29
Na_2O	1·08
	100·70

Since the crystalline minerals present are known to consist almost entirely of quartz and mica, the very respectable content of manganese, and much of the ferric oxide, would appear to have been brought into the deposit along with the organic matter. A portion of the iron is, as we have seen above, an integral constituent of the humus-like sediment; the clear caustic-soda extract from 1 gram of No. 3 yielded, on precipitation with acid, 0·29 gram of alkali-humus, the ash of which contained 0·023 gram of Fe_2O_3.

Brown Mud is found at all depths; in the same loch it usually occurs, as a surface-deposit, at lower depths than pale Clay. In well-marked depressions of a loch-bottom, and under comparatively stagnant water generally, it is the invariable sediment.

As to the origin of the organic constituent of Brown Mud, there can be no doubt that it is derived ultimately from the decomposition of vegetable matter. Much plant-refuse, such as leaves, twigs, etc., is imported into lochs, especially in autumn and winter, and a partially decayed compost of such is not uncommonly observed as a layer over the Brown Mud proper. The immediate remains of this refuse account for the organic deposit insoluble in alkali. But the dark amorphous ferruginous alkali-humus has all the appearance of having been precipitated, rather than formed *in situ*; moreover, it would be difficult to account for the loosely combined iron in it except by precipitation. From the experiments of Spring[1] we know that dissolved humus and ferric iron coagulate each other under the action of sunlight, whilst on the other hand there is certainly much iron in the ferrous state dissolved in peaty water. It appears probable, then, that alkali-humus is a chemical precipitate of insoluble iron humate, which has been sent down from the upper waters by the oxidation of a soluble iron compound, the latter being either ferrous bicarbonate or a combination of ferrous iron with perhaps a quite distinct form of humic acid. The precipitate is not of a permanent nature, but is slowly oxidised away, whilst the iron contained in it goes back into solution in the ferrous state ; in support of this the absence of humus in the clay underlying Brown Mud, and the exudation of iron from wet Brown Mud samples (see above, p. 264), may be mentioned. Iron thus seems to act as an oxygen-carrier in the breaking-down of vegetable debris.

The elimination of organic matter from a loch, however slow the process may be, and whatever its mechanism, must depend in the last resort on the supply of atmospheric oxygen to the loch waters. There rarely seems to be a sufficient excess of oxygen in the deepest waters of lochs to keep the bottom clean by purely chemical oxidation ; and the disposal of vegetable debris by direct fermentation into methane and carbon dioxide[2] is apparently inhibited, or much hampered, by peaty water. Hence in depressions of the bottom, where vegetable debris tends to collect by simple gravity, there is sure to be a shortage of oxygen, and Brown Mud is the staple deposit. Small lochs, again, which receive more vegetable refuse per unit area than large ones, may be, and often are, wholly carpeted with Brown Mud. Wherever Brown Mud is absent on the floor of a loch it may be inferred that there is either a brisk movement of the bottom water, a copious supply of dissolved oxygen, or a gradient too steep to afford lodgment to vegetable debris.

A special variety of this class of deposit may be termed Sulphuretted Mud ; it consists of Brown Mud containing ferrous sulphide, and is characterised by a colour approaching black and a smell of sulphuretted hydrogen. Free sulphur, due to the partial oxidation of sulphides, is always present. Sulphuretted muds are occasionally met with in the large Highland lochs, but only in the deepest hollows, or at an inflow of drainage from an inhabited spot. In the small lochs of the Hebrides, Orkney, Shetland, and the lowlands, where the water is as a rule comparatively stagnant and not peaty, they occur very frequently, and in many cases constitute the sole deposit. Their

[1] *Bull. Acad. Belg.*, t. xxxiv. p. 578, 1897.

[2] Hoppe-Seyler, *Zeitschr. Physiol. Chem.*, Bd. x. p. 401, 1886.

existence may be regarded as a certain indication that oxygen is not merely low in quantity, but altogether absent, in the bottom waters. The sulphur in them, which cannot well arise from the reduction of sulphates, as in sea-water,[1] owes its origin to the decomposition of vegetable or animal proteids. Since animal debris is much richer in sulphur than vegetable, Sulphuretted Mud is the more likely to be formed, the greater the supply of animal matter from the loch-waters or from outside. It may be remarked that, however black and fetid such a mud may be, the actual content of sulphur is always exceedingly small,[2] as the following figures for two deposits reeking of sulphuretted hydrogen show :—

	Ferrous Sulphide.	Free Sulphur.
1. Kirk Loch, Lochmaben, 23 feet .	0·17 per cent.	0·059 per cent.
2. Loch Harray, Orkney, 2 ,, .	0·22 ,,	0·041 ,,

4. Diatom Oozes

Whilst a stray Diatom here and there may be observed in almost any loch-deposit, especially in Brown Muds, patches of deposit occur in some lochs of which the bulk is composed of Diatom skeletons. Such deposits may be recognised at once by their lack of coherence. Of five Diatom Oozes noted, four are white, with a slight yellow discoloration due to clayey matter; these are from Lochindorb, Loch Allt an Fheàrna, 15 feet, Loch Assynt, 175 feet, and Loch an Duna (Lewis). The fifth, from Loch Frisa (Mull), 175 feet, is dark when wet, and dries to a mouse-coloured powder ; this deposit consists of Diatom frustules mixed with a good deal of humus, and quantitative particulars of its carbonaceous ingredient have been given above (p. 265). By extracting with very dilute caustic soda and determining the silica dissolved, information can be obtained as to the amount of diatomaceous silica present. Two of the deposits enumerated above gave the following figures for soluble silica :—

Loch Frisa, 175 feet, . . .	37·2 per cent.
Loch Allt an Fheàrna, 15 feet, .	68·1 ,,

The water combined with this silica cannot be satisfactorily determined unless exceptionally pure Diatom Oozes should happen to be available, and no attempt was made with the material at disposal. It would be interesting, however, to know something about this

[1] Murray and Irvine, *Trans. Roy. Soc. Edin.*, vol. xxxvii. p. 481, 1893.
[2] *Cf.* also Buchanan, *Proc. Roy. Soc. Edin.*, vol. xviii. p. 17, 1891.

constituent, because one would on theoretical grounds[1] expect the silica of fresh-water Diatoms to be slightly more hydrated than that of marine Diatoms; the latter is supposed to attach to itself about 8 per cent. of water.[2]

The Diatom species dominant in these five deposits, for the determination of which I am indebted to the courtesy of Professor G. S. West, of the University of Birmingham, are the following:—

Lochindorb . . .	*Navicula major.*
	Surirella robusta, var. *splendida.*
Loch Allt an Fheàrna .	*Melosira distans.*
	Surirella robusta, var. *splendida.*
Loch Assynt . . .	*Epithemia Hyndmanni.*
Loch an Duna . .	*Cyclotella compta.*
	Surirella robusta, var. *splendida.*
Loch Frisa . . .	*Cyclotella compta*, var. *radiosa.*

5. Ochreous Muds

Ochreous deposits are distinguished by a high content of limonitic iron, which gives them a pronounced red colour. Besides limonite they contain the inevitable admixture of Clay, and always more or less organic matter; as the proportion of the latter decreases, the colour becomes more brilliant. Good examples of Ochreous Muds are found in Loch Ness, 600 feet; Loch Laoghal, 51 feet; and Loch Assynt, 77 feet. An analysis of the first-named ("Ferruginous Mud") has already been published;[3] it shows 24½ per cent. of total ferric oxide. The Loch Assynt sample is the purest, *i.e.* most ferruginous, specimen hitherto met with, and has a fine Venetian red tint; the organic matter (see above, p. 265) is trifling in amount. A mineral analysis of this deposit gave the following results:—

Total ignition loss .	12·68
SiO_2 . . .	13·60
Al_2O_3 . . .	13·62
Fe_2O_3 . . .	55·49
MnO_2 . . .	1·89
CaO . . .	0·86
MgO . . .	0·92
K_2O . . .	0·95
Na_2O . . .	0·57
	100·58

[1] Spring and Lucion, *Zeitschr. anorg. Chem.*, Bd. ii. p. 195, 1892.

[2] *Challenger Report on Deep-sea Deposits*, p. 212, 1891. There is, however, room for revision here; the analysis on p. 212 points to 6½ per cent. rather than 8 per cent.

[3] *Geogr. Journ.*, vol. xxxi. p. 58, 1908.

Almost all the iron was found to be capable of extraction by moderately concentrated hydrochloric acid (viz. 55·2 per cent. Fe_2O_3). The predominant ingredient of the deposit was identified under the microscope as limonite in small amorphous grains, mean diameter 0·01 mm.

There appears to be a genetic connection between Brown Muds and Ochreous Muds, inasmuch as examples of Brown Mud in progressive stages of limonitisation are met with. This suggests that the ochreous matter may be a decomposition-product of ferruginous humus. Ochreous deposits are of highly localised occurrence, and must have originated either in a local supply of iron (as from chalybeate springs), or in a local concentration of iron pre-existing in the deposits or waters of a loch. For the former hypothesis there is no tangible evidence. It appears more probable that iron humates, dissolved in the loch-water or insoluble in the deposits, encountered a current of water strongly charged with atmospheric oxygen, reaction taking place with formation of limonite and liberation or destruction of humus-acids. As for precipitation of limonite from the water, this could only occur if there were extremely little organic matter in solution, since, so long as humic acid is in excess, not limonite, but insoluble iron humate, goes down.[1] We are left to conclude, then, that Ochreous Muds are formed *in situ* by the oxidation of Brown Muds—whether directly, or through the agency of bacteria,[2] must be left undecided. The humus of Brown Muds, as we have seen, holds in combination a considerable amount of iron, which at one time must have been in solution in the loch-water, and at a still earlier stage must have been leached out of minerals by dissolved humic acids. It will be noted that the best examples of Ochreous Mud occur in deep water, where a mass of humus capable of leaving a tolerably thick layer of limonite may have had opportunity to accumulate. Whatever be the origin of lacustrine limonite, its formation and existence must certainly be bound up with an excess of dissolved oxygen in the adjacent waters.

6. Calcareous Deposits

It will have been noted that no mention has been made in the foregoing pages of calcium carbonate, which plays so important a part in the deposits of the ocean and of lakes on the continent of Europe. Not a trace of this substance was found in any of the deposits from Scottish mainland lochs,[3] and the reason clearly is that the country is

[1] *Cf.* Spring, *loc. cit.*

[2] *Cf.* Van Bemmelen, *Zeitschr. anorg. Chem.*, Bd. xxii. p. 313, 1900, where references to the literature of iron-bacteria are given.

[3] Although there is a limestone formation of some magnitude at the eastern end of Loch Assynt, the twenty odd deposits from this loch, the floor of which

poor in lime, the limestone formations being both rare and exiguous. Not only, therefore, is no lime brought into the loch-bottoms as detritus, but also the waters are too soft to harbour a flourishing lime-secreting fauna, such as might give rise to deposits of biological calcium carbonate. Peaty waters, also, may be admitted to have a solvent action on lime which tends to prevent its deposition or secretion; but as it is, the Scottish loch and river waters find next to no calcareous material upon which to exert their powers. In those exceptional regions where limestone formations predominate we may expect to find lime on the floors of lochs. A case in point is the island of Lismore, from which four calcareous bottom-samples were brought, viz.:—

(1)	Loch Baile a' Ghobhainn,	2 feet, $CaCO_3$ =	91 per cent.
(2)	,, ,,	88 ,, ,,	61 ,,
(3)	Loch Fiart, . . .	58 ,, ,,	53 ,,
(4)	Loch Kilcheran, . .	60 ,, ,,	40 ,,

The calcareous matter consists of crystalline calcite in small fragments, with here and there a piece of snail-shell; it is, properly speaking, a biological precipitate, having been formed by the agency of phanerogamous aquatic plants,[1] which withdraw carbonic acid from the very hard water of these lochs, and cause the deposition of calcium carbonate around their stems. Deposits 2–4 are Brown Muds mixed with lime.

Not a single mainland deposit was observed to be calcareous. A sample with 75 per cent. of calcium carbonate was taken, oddly enough, from Loch Swannay in Orkney, which is not a limestone country. The deposit occurs under 8 feet of water at a spot where a patch of *Potamogeton* is reported, and this plant is doubtless responsible for its formation. Other bottom-samples from the same loch are quite free from lime.

Scottish Loch and Oceanic Deposits Compared

The general conditions which govern the formation of loch deposits have been indicated to some extent in describing the several classes of deposits. It is not uninstructive, in this connection, to compare the floor of the lochs with that of the ocean.

All subaqueous deposits owe their being to three distinct processes, viz.:—

(1) Importation of solid matter from land.

was exceptionally well sampled, were found to be quite free from calcium carbonate. It would have been interesting, in this connection, to know something about the content of lime in the loch-water.

[1] West, *Proc. Roy. Soc. Edin.*, vol. xxv. p. 968, 1905.

(2) Precipitation, biological or purely chemical, from the overlying waters.

(3) Decomposition and synthesis of matter at the bottom.

These agencies operate very differently in the lochs and in the sea, and the aqueous media also are very different; hence it is not surprising that lacustrine and oceanic deposits should show more points of contrast than of similarity.

(1) All the mineral matter at the bottom of a lake is derived by erosion from the surrounding country, either through direct wave-action on shore, or through the medium of affluent rivers. It is thus wholly "terrigenous," whereas of the floor of the ocean only a limited strip around the continental coast-lines answers to this description. Inorganic lake deposits, then, are essentially similar to terrigenous oceanic deposits, consisting of clastic debris of continental minerals with more or less clay, and having a finer grain the greater their distance from briskly moving water. *Oceanic* terrigenous deposits, however, undergo certain submarine modifications which are peculiar to sea-water as a medium: by the decomposition of (animal) organic waste within them they acquire an intimate admixture of fine carbonaceous matter, whilst the iron within them is partially reduced from the ferric to the ferrous state; or, again, through the activity of bacteria which reduce the sulphates of sea-water, ferrous sulphide may be formed within them. These processes are carried out by the aid of bottom-living animals or bacteria, and produce the Blue Muds, a class of deposit which has no real analogue in the Scottish lochs, in the peaty waters of which there is no abyssal fauna to speak of and bacterial life is at a minimum. It is noteworthy that a blue-grey Clay resembling Blue Mud comes into existence at the bottom of the Lake of Geneva,[1] where there is plenty of biological activity in the abyssal regions. On the other hand, *lacustrine* mineral deposits are subject to organic contamination of a kind unknown in the sea, in that they may become charged with the humus which results from the decay of vegetable matter. Humus in the Clay of the Scottish lochs, however, does not tend to be degraded further to the condition of the black carbonaceous constituent of Blue Mud; this again may be accounted for by the absence of an abyssal fauna. As regards the mineral detritus in terrigenous deposits, it is qualitatively much the same in the lochs and the ocean. Detrital calcium carbonate, which does not exist in the lochs and does not reach the bottom in the ocean, occurs, however, in the lakes of Switzerland and Northern Europe as calcareous mud.

(2) A most important factor in the formation of submarine deposits is the animal life with which the ocean swarms. More than a third

[1] Forel, *Le Léman*, t. i. p. 119, 1892.

of the floor of the ocean is covered with dead calcareous shells (Globigerina Ooze) fallen from above, and large areas also are composed of siliceous skeletons (Diatom Ooze and Radiolarian Ooze). These oozes consist of inorganic material which has been precipitated by biological agencies out of solution in the sea. Such deposits play but an insignificant part in lakes. It is clear that, even if the requisite forms of life were present, there could not be much precipitation of calcium carbonate in lakes, seeing that there are only 30 to 40 parts per million of calcium in normal soft lake-water, whereas in sea-water there are about 400 parts per million. Apart from the sparse fragments of large shells occasionally found near shore, calcareous matter seems never to exist in the deposits of Scottish mainland lochs.

Such calcareous deposits as have been found in island lochs are products of vegetable life, and are thus comparable to the coccoliths and rhabdoliths of deep-sea deposits. Calcium carbonate secreted by plants, especially algæ, is a not unimportant constituent of Danish lake deposits.[1] On the whole, however, it may be said that, whilst submarine lime is wholly of biological, that of lake-deposits is mainly of detrital, origin.

Diatomaceous deposits are occasionally met with in the lochs, as recorded above. As compared with oceanic Diatom Oozes, they contain more clayey silt, and they are free from the lime which invariably accompanies their oceanic analogues. There is reason to believe that peaty water such as that of the lochs is, if anything, richer in silica than that of the ocean. If, in spite of this, diatomaceous lake-deposits are somewhat uncommon, the reason may be either that sea-water is relatively a kindlier medium for this form of life, or that dead Diatom frustules are redissolved more rapidly in loch water.

Peaty water carries in solution a certain amount of iron existing as soluble humate, a solute which is absent or insignificant in ocean-water. Brown Mud, as we have seen above, appears to be partially derived from this source, and would in so far be classifiable as a precipitated deposit. Anything like Brown Mud is unknown at the bottom of the open sea, since precipitated humus is rapidly cleared away by bottom-living animals. A comparison of Loch Ness with a similarly shaped and environed salt-water loch, such as Loch Fyne, is instructive in this respect. Both lakes exist under similar conditions, but the former holds fresh water and the latter sea-water; the result is that Brown Mud accumulates at the bottom of Loch Ness, whilst in Loch Fyne the bottom is kept comparatively clean and free from vegetable organic matter.

(3) Decomposition of minerals is much the same process in oceanic as in fresh water. Alkalies, calcium, and magnesium are eliminated,

[1] Wesenberg-Lund, *Studier over Sökalk*, etc., p. 154, Copenhagen, 1901.

water of hydration is taken up, and the result is clay. It has been mentioned that submarine clayey deposits are in a far more advanced stage of decomposition, *i.e.* contain far more clay proper, than lacustrine ones. This is due not to a more powerful corroding action on the part of sea-water, but rather to the greater geological age of submarine deposits. The continual transportation of fine suspended argillaceous matter from land into the ocean is also to be reckoned with.

Except in quantities of 1 or 2 per cent. at the utmost, there is no organic matter in deep-sea deposits. The little (mainly animal) that reaches the bottom is rapidly oxidised away or consumed by the bottom-living fauna. The lochs are in a very different case. Here there is a plentiful influx of dead vegetable matter—more than the available supply of dissolved oxygen can cope with. This debris decays as far as the humus stage, instead of being broken down to carbonic acid; the humus accumulates in combination with iron, and becomes in effect the characteristic lacustrine deposit. It is interesting to observe the vicissitudes of iron in the two media. In a loch we find the Clays much paler, that is, less ferruginous than deep-sea Clays, and a continual interchange of iron between the water and the bottom-deposits is going on; whilst the Brown Muds lock up a good deal of iron (and manganese) and tend, if exposed to oxidising conditions, to become ever more ferruginous. The concentration of iron as limonite or siderite in clay-ironstone and bog-ores is in fact peculiar to fresh water. In the sea, on the other hand, if we disregard the minor, and up to the present inexplicable, concentration of iron in glauconite, the career of this element is uneventful and ends with ferruginous Clay.

It is scarcely necessary to point out that in lakes nothing similar to the vast areas of oceanic Red Clay, which substance is produced by the decomposition *in situ* of volcanic silicates, need be expected; indeed, no lake is large enough to contain regions which, with respect to the deposits, might be termed "pelagic."

BIOLOGY OF THE SCOTTISH LOCHS

By JAMES MURRAY, F.R.S.E.

PART I

THE BIOLOGY IN RELATION TO ENVIRONMENT

INTRODUCTION

During the five years of the existence of the Lake Survey, 562 lochs have been surveyed. Biological collections were made in nearly all of those lochs, and more than 400 of these collections have been examined. Usually only a single collection of plankton was taken in each loch; but in Loch Ness and a few other lochs it was possible to study the biology more thoroughly, and to examine the littoral and abyssal regions also. From a biological survey made in this manner it is hardly possible to make generalisations of any value. Each loch being examined only once, and the survey being carried on almost at all seasons of the year, the lochs cannot even be fairly compared one with another. The amount of difference found between the plankton of different parts of the country may in part arise from the fact that they were examined at different seasons of the year. This is the more probable since it is known that fresh-water plankton is very uniform over vast areas. Despite this difficulty, it is, however, certain that some very interesting facts in the distribution of plankton organisms can be ascertained from an examination of these collections. Their chief use, in the meantime, is to enable a census of the inhabitants of the Scottish lochs to be made—very imperfect, certainly, but of some value to special students, as offering a large body of facts not readily got together.

The biological survey was concerned solely with the Invertebrata among animals, and chiefly with the microscopic Algæ among plants. Of the Vertebrata, the only class which is conspicuous among true lacustrine animals, the Fishes, had already been the subject of much special study. The same may be said of the aquatic birds; and the other classes of Vertebrata—Mammalia, Reptilia, Batrachia

—are of little importance in connection with lakes. In the Invertebrata, on the other hand, there was a vast field, very partially explored in this country, the chief work having been done on the Crustacea by Dr Scott. The Phanerogamia and higher Cryptogamia were only studied by the Lake Survey in a few districts; but the microscopic Algæ, occurring in the plankton, were important in all the collections.

In this first part of the paper the biology of the different parts of the lakes is first studied—the open water, the margin, the bottom—then the distribution, origin, etc. In the "Census of Species" given in Part II., only those lochs are taken into account which were bathymetrically surveyed, in order that the biological report may strictly correspond with the bathymetrical. A biological examination was made of many lochs not otherwise surveyed, and some interesting facts thereby added to our knowledge ; but such facts will not be treated of here.

The distribution of some 700 species through more than 400 lochs offers difficulties in regard to its presentation in useful and convenient form. To give it in tabular form would need a large number of tables. While some of the plankton species have been found in nearly every loch, other species have been found in only one or two, or at any rate in very few lochs. There is no reason to believe that most of these latter are really more restricted in their distribution than the others. Many lochs may have been visited when those species were not in season; but the main reason for the inequalities in the number of records for different species is that the margins of the lakes, where the major part of the life resides, could only be examined in a few instances. The distribution might be more concisely tabulated by grouping the lochs into districts, but even thus the records would be so very inadequate and unequal as to be actually misleading, and it is doubtful if such tables would serve any good purpose. There are, of course, some species which are believed to be really rare or restricted in distribution. Those which, though not rare, have well-marked limitations of range, will be treated in a special section on Distribution. Those which are rare or sporadic in occurrence will be referred to in the notes on the species which follow the list of species in each class. In this census it may be assumed that species not specially remarked upon in the notes are fairly generally distributed over the country.

THE PLANKTON

An understanding of the character of the plankton of the Scottish lochs may be obtained by considering, first, the features in which it agrees with the plankton of the rest of Europe, and the world generally, then the special peculiarities which distinguish it. Before doing so it will be necessary to examine the composition of the plankton. The number of organisms which have been taken in the plankton-collections, *i.e.* in the open water of the lochs, is very considerable. On a scrutiny of the lists of species taken in the plankton-nets it is found that a large number of them must be excluded as not truly belonging to the plankton. This results from the narrow form of most of the larger lakes, which makes it easy for littoral forms to be driven out to the open water during storms. The same effect is produced in broad but shallow lakes by the stirring up of the muds, by which bottom forms become mixed with the true plankton. The plankton is very often impure, but experience teaches what are the true plankton organisms, and, moreover, in the larger lakes very pure collections may be got after a period of calm weather. Excluding casuals, the plankton lists are not very extensive.

The relative frequency of the species in the following lists is indicated by only three terms, *general*, *local*, and *very local*. It is judged that more accurate discrimination is not at present possible.

Zooplankton

Crustacea.—*Diaptomus gracilis*, Sars. General.
D. laciniatus, Lillje. Local.
D. laticeps, Sars. Local.
D. wierzejskii, Richard. Local.
Cyclops strenuus, Fischer. General.
Diaphanosoma brachyurum, Liévin. General.
Holopedium gibberum, Zaddack. General.
Daphnia hyalina, Leydig. General.
Bosmina obtusirostris, Sars. General.
B. longirostris (Müll.). Local.
B. coregoni, Baird. Very local.
Polyphemus pediculus (Linné). General.
Bythotrephes longimanus, Leydig. General.
Leptodora kindtii (Focke). General.

Rotifera.— *Floscularia pelagica*, Rouss. ? Local.
Conochilus volvox, Ehr. General.
C. unicornis, Rouss. General.
Asplanchna priodonta, Gosse. General.
Polyarthra platyptera, Ehr. General.
P. euryptera, Wier. Local.
Triarthra longiseta, Ehr. Local.

Anuræa cochlearis, Gosse. General.
Notholca longispina, Kell. General.
Gastropus stylifer, Imhof. ? Local.
Plœsoma hudsoni, Imhof. Local.
P. truncatum, Levander. Local.

Protozoa.— *Nebela bicornis*, West. Very local.
Raphidiophrys conglobata (Greeff). ? Local.
R. pallida, F. E. Schulze. ? Local.
Clathrulina elegans, Cienk. Local.

In addition to the 30 species above enumerated, there may be some doubt as to whether some of the commonest casual species might not be included in the plankton. *Sida crystallina* is very commonly captured in the open water, though the possession of the remarkable sucker would lead one to suppose that it would always frequent the weedy margin. *Alonopsis elongata* is still more frequently got in the open water, even of the largest lakes, though never in great abundance. *Furcularia reinhardti* is quite common in the plankton; but it is such a ubiquitous species, living in streams, ponds, and even in the sea, that it cannot be considered proper to any situation. *Synchæta*: the various species of this genus are often reckoned in the pelagic fauna, but they so rarely occur in the larger lochs, except near shore, that I regard them as pond species. *S. tremula* is perhaps most frequent in the larger lochs, *S. pectinata* is common in small lochs and ponds, and *S. grandis* has only once been noted.

Arcella, *Cyphoderia*, and a few other Rhizopods are pretty frequent in the plankton, but still, I think, casual.

Of the 30 species in the list it may be said of several of them that they are too rare, or too little is known of them, to decide whether they are true plankton species in the Scottish lochs. *Bosmina coregoni*, only known in two of the lochs, is included because Dr Wesenberg-Lund gives it as usual in the lake plankton of the great Central European plain. *Nebela bicornis* is included because its hyaline character seems to indicate fitness for a pelagic life, and its discoverer only found it in the plankton (of Loch Shiel). A single example was got in Loch Ness. Two species of *Raphidiophrys* are known to be in Loch Ness from Dr Penard's researches, and one species in Loch Rannoch. They may be common.

The case of *Clathrulina elegans* is peculiar. It is frequent, especially in the great lakes, but is by no means general in its distribution. It is usually only the skeletons that are found, rarely encysted animals, and only once (in Loch Lochy) were they found with the pseudopodia extended.

Phytoplankton

The number of vegetable organisms in the plankton collections is much greater than that of animals, and it is much more difficult to assign them their true positions, whether true plankton organisms or casual. It is not intended to give full lists here, as these would almost coincide with the lists in the "Census of Species."

All the Chlorophyceæ in the list (about 150 species, of which about 120 are Desmids) were obtained in the plankton nets. A large proportion must be casuals, washed out from the peat-bogs, etc. These figures may be compared with those given by Messrs W. and G. S. West,[1] who have recorded nearly 200 Chlorophyceæ for the Scottish lochs, about 150 being Desmids.

As I cannot pretend to the knowledge necessary to select from our long list the true plankton Desmids, Messrs West's list of 44 species is here transcribed. I would be inclined to somewhat extend the list.

Desmids.—*Gonatozygon monotænium*, De Bary.
Genicularia elegans, West.
Closterium kützingii, Näg. General.
Euastrum verrucosum, Ehr. General.
Micrasterias mahabuleshwarensis, Hobson. Very local.
Cosmarium contractum, Kirchn.
C. depressum (Näg.).
C. abbreviatum, Racib.
Xanthidium antilopeum (Bréb.). General.
X. subhastiferum, West. Local.
X. controversum, West. Local.
Arthrodesmus incus (Bréb.). General.
A. quiriferus, West.
A. crassus, West.
A. triangularis, Lagerh.
Staurastrum dejectum (Bréb.). Local.
S. curvatum, West. Local.
S. jaculiferum, West. General.
S. megacanthum, Lund. Local.
S. cuspidatum, Bréb.
S. inelegans, West.
S. longispinum (Bail.). Local.
S. brasiliense, Nordst. Local.
S. grande, Buln. Local.
S. brevispinum, Bréb.

[1] *Trans. Roy. Soc. Edin.*, vol. xli. pp. 477–518, 1905.

S. lunatum, Ralfs. General.
S. aversum, Lund.
S. subnudibrachiatum, West.
S. teliferum, Ralfs.
S. erasum, Bréb.
S. pseudopelagicum, West. Local.
S. paradoxum, Meyen. General.
S. gracile, Ralfs. General.
S. anatinum, Cooke and Wills. Local.
S. ophiura, Lund. Local.
S. furcigerum, Bréb. Local.
S. sexangulare (Buln.). Local.
S. arctiscon, Ehr. Local.
Spondylosium pulchrum (Bail.).
Desmidium graciliceps (Nordst.).
D. coarctatum, Nordst.
D. occidentale, West.
Hyalotheca mucosa, Ehr. General.
H. neglecta, Racib.

Several of these are not in the survey list, and it is to be noted that in many cases the species occurs in the plankton under special varieties, not here specified, as it is only intended to indicate what species are, under some form, to be regarded as naturalised in the plankton.

Other **Chlorophyceæ.**—26 species (Messrs West 44 species).
Myxophyceæ.—10 species (Messrs West 21 species).
Peridiniaceæ.—*Peridinium* sp.
Glenodinium sp.
Ceratium hirundinella, Müll. General.
C. cornutus (Ehr.). Local (or casual).
Flagellata.— *Mallomonas* sp. General ?
Dinobryon. Several forms common.

Diatoms.—The list of Diatoms is very poor, numbering only some two dozen species, whereas Messrs West found about 60. Most of these they regarded as casual, and the small list of true plankton species, here transcribed, only numbers about 20 species.

Tabellaria fenestrata (Lyngb.). General.
T. flocculosa (Roth.). General.
Fragilaria crotonensis (A. M. Edw.). Local.
Asterionella formosa, Hass. General.
A. gracillima, Heib. General.
Eunotia pectinalis (Kütz.).

Navicula major, Kütz.
Vanheurckia rhomboides (Ehr.).
Surirella biseriata (Bréb.).
S. robusta, Ehr. General.
Synedra ulna (Nitzsch.).
Melosira granulata (Ehr.).
Amphipleura pellucida, Kütz.
Rhizosolenia longiseta, Zach. Local.
R. eriensis, H. L. Sm. Local.
Cyclotella (several species).

A brief analysis of the preceding lists will prepare us for a comparative study with the rest of Europe. The species marked in the list as "general" are almost universal in the lochs of the mainland, and usually in the islands also. Those marked "local" have well-marked limits in their distribution, though they may be very common, and may even be in every part of the country, but only in a small proportion of lochs. Those marked "very local" are only known in a few lochs. Those having no such indication are insufficiently known, or at least the collections do not furnish sufficient information, and such must be sought elsewhere.

Zooplankton.—The list contains 14 Crustacea, 12 Rotifera, and 4 Protozoa. 15 species (9 Crustacea and 6 Rotifera) are generally distributed in the lochs; 15 species are considered local.

Half of the generally distributed Crustacea are found all the year round—*Diaptomus gracilis*, *Cyclops strenuus*, *Daphnia hyalina,* and *Bosmina obtusirostris.* The others have a limited season—*Holopedium*, *Polyphemus, Bythotrephes*, *Leptodora*, *Diaphanosoma.*

All the generally distributed Rotifera appear to persist throughout the year. For some of the species there is hardly enough evidence to prove this, but at all events they are found throughout summer, autumn, and early winter, and in early spring they are present (*Asplanchna* bearing viviparously) before the larger lakes begin to rise in temperature.

Phytoplankton.—Apart from the Desmids and Diatoms, no analysis of the phytoplankton will be attempted, as Dr Bachmann discusses these in his paper.[1]

I have indicated in the list 9 Desmids and 5 Diatoms which appear to be generally distributed. They are: *Closterium kützingii*, *Euastrum verrucosum*, *Xanthidium antilopeum*, *Arthrodesmus incus*,

[1] See Bachmann, "Vergleichende Studien über das Phytoplankton von Seen Schottlands und der Schweiz," *Archiv f. Hydrobiologie u. Planktonkunde*, Bd. iii. p. 1, 1907. To include the dozens of species recorded by Bachmann in their proper places would involve rewriting this article; the reader is therefore referred to the work itself.

Staurastrum jaculiferum, *S. lunatum*, *S. paradoxum*, *S. gracile*, *Hyalotheca mucosa; Tabellaria fenestrata*, *T. flocculosa*, *Asterionella formosa*, *A. gracillima*, *Surirella robusta.*

Of the Peridiniaceæ only *Ceratium hirundinella* can be definitely set down as "general," though a species of *Peridinium* (*P. tabulatum?*) is very frequent.

The 2 species of *Asterionella* are indicated as general, but this is rather misleading, as neither species is distributed all over the country. Messrs West are inclined to regard both forms as extremes of the same species, and it is intended to indicate that *Asterionella*, in one form or other, is in almost every loch.

Dinobryon is found in most lochs, but no one form is "general."

Mallomonas is probably "general," but if so, has been frequently overlooked, as might from its small size be expected.

There are thus altogether only some 29 organisms, or equal numbers of animals and plants, which can be regarded as generally distributed in the Scottish plankton. These figures leave out of account certain groups of phytoplankton, at present under study.

Few of these species ever become dominant in the plankton, to the extent of colouring the water or rendering it turbid. Several of the Crustacea (*D. gracilis*, *C. strenuus*, *Holopedium*, *Daphnia*, *Bosmina*) may do so.

Of the Rotifers, *Asplanchna*, from its large size, most readily dominates the plankton, but has only rarely been observed to do so. *Notholca longispina* has on occasion rendered the collections brick-red, and somewhat affected the transparency of the water. *Anuræa cochlearis* and *Polyarthra platyptera* have, in small lochs, contributed considerably to the turbidity.

Ceratium hirundinella is frequently the dominant organism for a season, and occasionally renders the water turbid. No one species of Desmid is ever conspicuously dominant, but often an aggregation of many species, all abundant, gives the character to the plankton.

The organisms most commonly greatly predominating in the water, so as to produce the phenomenon of "flowering," are not found among the most generally distributed species. Those are among the casual species, chiefly Myxophyceæ (*Anabæna*, *Clathrocystis*, etc.), or less commonly Chlorophyceæ (*Volvox*, etc.).

Seasonal Variation.—The seasonal variation in the composition of the plankton is, on the whole, but slight; although, as it is chiefly exhibited among the largest Crustacea, it produces conspicuous differences. The four commonest plankton Crustacea, *Diaptomus gracilis*, *Cyclops strenuus*, *Bosmina obtusirostris*, and *Daphnia hyalina*, remain all the year round in Loch Ness, and have been frequently taken in winter in smaller lochs, though in some of these they may have a resting season, as in some lochs at high elevations only *C. strenuus* is found at the end of winter. The other Crustacea have a seasonal limitation.

All the commonest plankton Rotifers also persist all the year round. The season at which a summer species appears in different lochs is affected by climate, and by the volume of the lochs. In small lochs which quickly warm up in summer they appear early; in larger lochs which remain longer cool they may appear months later. No precise limits for the seasonal range of the different species can be given, as most lochs were visited only once; but the earliest and latest dates at which they have been observed may be indicated.

Holopedium.—Earliest appearance noted, end of April 1903, near Inverness; latest, October 1903, also near Inverness.

Leptodora.—Earliest, May 1902, in the Ness basin. In Loch Ness it was present from July till November 1903—in October males appeared, and in November they predominated.

Bythotrephes.—Earliest, Loch Ruthven, end of April 1903; latest, November 1903, Loch Ness.

Polyphemus.—Earliest, middle of April, Ness basin; latest, Loch Laoghal, Sutherland, October 1902. In Loch Ness it was found only from July to September.

Diaphanosoma brachyurum.—Earliest, near Oban, May 1903; latest, W. Ross, October 1904.

Latona.—Earliest, Tay basin, May 1903; latest, E. Ross and Galloway, August.

Diaptomus laciniatus.—Earliest, June 1904, Ness basin; latest, October 1902, Sutherland.

D. wierzejskii.—Earliest, May 1904, North Uist; latest, October 1902, Sutherland.

The seasonal range above indicated cannot be trusted as giving the true limits, except for those species (*Leptodora*, *Bythotrephes*, *Polyphemus*) which live in Loch Ness. The lochs in which the other species live have not been visited earlier or later than the dates given. Some of them may endure longer in the season, or even possibly all the year round.

The seasonal variation of the phytoplankton cannot be indicated with any precision Loch Ness, which alone has been systematically examined during a whole year, has a very meagre phytoplankton. All that can be said about the phytoplankton in this connection is derived from single observations of each loch.

Flowering of the Water.—In the great lakes a marked "flowering" has never been seen at any season. In Loch Lomond there was what Dr Bachmann described as a "Wasserblüthe" in August 1905, though the Algæ did not form streaks or patches on the surface, but could be seen floating scattered through the water.

A distinct "flowering" due to Chlorophyceæ has been seen in a shallow loch as early as July. The phenomenon was commoner in the autumn, in August, and especially in September, among the northern lochs, and was generally caused by Myxophyceæ (*Anabæna*, *Oscillatoria*, etc.).

In contrast to this summer and autumn "flowering," some lochs of considerable size (Loch Earn, St Mary's Loch) flowered in mid-winter, when the water was coolest. These lochs had clear water in summer when the Algæ were scarce, but became more or less turbid from the abundance of vegetable life in winter.

Temperature in relation to Plankton.—In respect of the temperature of the water, as affecting the biology, Scottish lochs fall into two classes—those which do not freeze in winter, and those which do freeze. The climate of Scotland is so temperate that no lochs are in normal winters frozen over for long periods, as they are in Europe generally. The smaller lochs may be frozen over for a few days, or a few weeks, several times in the course of the winter. The distinction between the two classes of lakes is, however, quite sharp.

The first class contains lochs of such a size that an ordinary winter is not sufficiently long to cool them below the maximum density point of water. Their minimum temperature is therefore nearly 40° Fahr., and the larger lakes seldom cool to within several degrees of this. The volume of water which prevents cooling below this point in an ordinary winter also prevents undue heating in summer, and the characteristic of these lakes is the small annual range of temperature, rarely reaching 20°·0 Fahr. This very temperate climate must be of great importance to the inhabitants of the lakes, and might be expected to reduce seasonal change to a minimum.

The second class contains lakes which cool sufficiently in an ordinary winter to cause them to freeze from time to time. The minimum temperature of these lakes may be anything down to freezing point, but it is rarely that anything less than 35°·0 is recorded in the water beneath the ice.

A temperature of 35°·0 has only been noted in very shallow lochs, and more usually, when the ice is broken over fairly deep water, a temperature of just about maximum density point is found. Lochs shallow enough to freeze in winter are also likely to become greatly heated in summer. These lochs have therefore a much higher annual range of temperature. It is rarely that any Scottish loch reaches a higher temperature than 64°·0 Fahr., so that the extreme range even for small lochs is only about 30°·0—very much less than the range in the shallow Continental lakes. Even so far north as Denmark the annual range seems to be about 10°·0 Fahr. greater; in the great Balatonsee of Hungary it is much higher—nearly 50°·0 Fahr. The greater range of temperature will favour seasonal variation. The higher summer temperature will be likely to encourage a richer fauna and flora; the low winter temperature will be unfavourable to life. An exceptionally severe winter may cause some of the smaller lochs of the first class to be for a time transferred to the second.

We are not in a position to trace the actual relation of the life-changes throughout the year to the changes of temperature, except in the case of Loch Ness, which may be taken as a fair type of the first class. That loch was examined regularly for more than a complete year. Loch Morar has been examined at all seasons, but irregularly and at long intervals. Several lochs which freeze in winter have been examined in midsummer and in midwinter.

In the great lakes which never freeze there is no very marked decrease in the quantity of organisms in winter. Many of the species persist all the year round; but as those which are absent in winter are the most conspicuous of the Crustacea, the difference between the winter and the summer plankton appears rather striking. *Holopedium*, *Polyphemus*, *Bythotrephes*, and *Leptodora* are all absent during a part of the year.

Cosmopolitan Element in the Plankton.—For information as to the general plankton of Europe and other regions I am mainly indebted to various papers by Dr Wesenberg-Lund, who has made wider comparative studies of plankton.

Only those species which are generally distributed over Scotland can be taken into account in comparing the plankton of Scotland with that of Europe generally. The animals which are dominant or common both in Scotland and the rest of Europe are: *Diaptomus gracilis*, *Daphnia hyalina*, *Diaphanosoma brachyurum*, *Leptodora kindtii*, *Conochilus unicornis*, *Asplanchna priodonta*, *Polyarthra platyptera*, *Anuræa cochlearis*, *Notholca longispina*, *Ceratium hirundinella*, and *Asterionella*.

All of these, according to Dr Wesenberg-Lund, belong to the general plankton association of the great European plain, or are even cosmopolitan.

Peculiarities of the Scottish Plankton

The Scottish plankton differs from the plankton of the Central European plain and from the cosmopolitan fresh-water plankton in several respects. The most striking peculiarity is the extraordinary richness of the phytoplankton in species of Desmids, shared only, in anything like equal degree, by the plankton of the Irish lakes. The next feature of importance is the conspicuous Arctic element in the plankton Crustacea. A third element is the absence or comparative rarity of some of the species commonest in the general European plankton. Another peculiarity is the very local distribution of some of the Crustacea and many of the Desmids.

The Desmid Flora.—Some 200 species of Desmids have been found in the Scottish lochs. Making the greatest allowance for casual species, there still remain 50 or more true plankton species. Sometimes as many as 50 species, including casuals, are found together in one loch. There is nothing like this elsewhere in European lakes, where, as a rule, there are no Desmids, or only a few species. The nearest approach to the condition of matters which obtains in Scotland is found in Scandinavia and Finland, where a number of the Scottish species occur. In a recent report on the Swiss Alpine lakes, Tanner-Füllemann[1] states that the Schönenbodensee is relatively rich in Desmids, 19 species being recorded.

Various attempts have been made to account for the great richness of our Desmid flora. Dr Wesenberg-Lund attributes it to the peaty character of the water. Messrs West likewise attribute it to the absence of lime and presence of humic acid, but they further consider that the richest Desmid flora is found in lochs lying in the Older Palæozoic rocks. A connection has been suggested between the heavy rainfall and the abundance of Desmids. There can be no doubt, as pointed out by Messrs West, that the abundance is not due to species washed out from peat-bogs. There are many well-marked pelagic species which appear to have been long established in the lochs, and are rare in the peat-bogs.

No doubt the peaty water is favourable to the increase of the Desmids, but neither of these explanations sufficiently accounts for the restriction of this Desmid flora to the British Isles. There are Older Palæozoic rocks and peat-bogs enough elsewhere in Europe, and no doubt lochs with peaty water in moorland districts. The lochs possessing the Desmids are not exclusively among the Older Palæozoic rocks; many of them lie partly or wholly among drift, and this over rocks of various ages. The means of dispersal from loch to loch are easy, and might permit of their distribution over the whole country, and into other countries, as rapidly as is known to be the case with Crustacea and Rotifers. There are also many peaty lochs among the Older Palæozoic rocks which have not the characteristic Desmids.

In view of all these facts, it seems to me that the prime factor in restricting these Desmids to certain regions must be climatic.

[1] *Bull. Herb. Boiss.*, sér. 2, t. vii., 1907.

Differences in the chemical properties of the water may account for local differences in the abundance of the Desmids. Most of the lochs rich in Desmids are near the sea-board, and those which are farthest removed from it are at considerable elevations. The region occupied by these lochs partly coincides with the distribution-area of some of the more local of the Arctic Crustacea.

European Species rare or absent in Scotland.—A number of species, dominant in the lakes of the European plain, are here rare or local, or they are entirely absent. *Diaptomus graciloides* is absent; *Bosmina coregoni* is very rare; *Hyalodaphnia cucullata* is believed to be very rare; *Bosmina longirostris* is very local.

The blue-green Algæ, though often conspicuous enough, are not so generally dominant; and the Diatoms, though present, are unimportant.

Dr Wesenberg-Lund further regards as belonging to the cosmopolitan stock certain Rotifers which are rare or local in the Scottish lochs, though common enough in other situations: *Notholca striata*, a pond species, rare at the margins of lakes; *Anuræa aculeata*, very rare, and only in small lakes; *Triarthra longiseta*, frequent in lakes, but by no means general, and absent from the great lakes.

Arctic Element.—The Arctic element in the Scottish plankton is very important. The Arctic species of Crustacea are *Holopedium gibberum*, *Bythotrephes longimanus*, *Daphnia hyalina*, *Bosmina obtusirostris* (= *B. arctica*, Lillje.), *Cyclops strenuus*, *Diaptomus laticeps*, *D. laciniatus*. As several of these species are among the permanent inhabitants of the lakes, which persist throughout the year (*Daphnia*, *Bosmina*, *Cyclops*), and some of the others are among the largest species, and are generally distributed (*Holopedium*, *Bythotrephes*), the Arctic element is clearly the dominant one in the Scottish plankton.

Distribution of the Plankton.—The distribution of the species in the lochs will be considered in a special section. Here the general features only, which give the special character to the Scottish plankton, will be dealt with. Of the 200 species of animals and plants which have been found in the plankton collections, probably about one-half should be regarded as casuals. The remaining 100 species are not all equally distributed over the country. Many are so rare, or the information about them is so scanty, that the study of their distribution would serve no purpose.

About 30 species are generally distributed. Many of the others are confined to the western half of the country, or to the extreme north, or they are very local or quite sporadic in their occurrence.

Diaptomus laciniatus and *D. laticeps* are irregularly distributed over the central, western, and northern counties; *D. wierzejskii* is limited to the extreme north and west, especially the islands; *D. gracilis* is almost confined to the mainland and nearer islands, and appears to be absent from most of the outer islands, both in the west and the north.

Comparatively few of the Desmids are generally distributed; the great majority are limited to the western half of the country, and are by far most abundant in Sutherland and the Outer Hebrides.

Vertical Migration of the Plankton.—Although few observations on this subject were made, they demonstrate a diurnal migration of considerable amount. Collections were made at short intervals during a day and night. It is not easy to demonstrate migration in the case of animals which are distributed from the surface to a depth of, say, 100 feet or more; but in the case of *Leptodora*, which during the day is usually only to be found at some distance below the surface, the migration is very evident. On the occasion in question *Leptodora* was only in the deeper collections during the day, and immediately after dark it was abundant at the surface. The migration must have been very rapid. There was also a very marked increase in the total quantity of the larger plankton organisms during the night—*Daphnia* and *Diaptomus gracilis*, at least, having come from the deeper layers to the surface. On a subsequent occasion, in calm weather, with full moon, no *Leptodora* was found in the surface collections after nightfall.

Seasonal Change of Form.—It is generally believed that some pelagic animals become more elongate in summer, the spines of others become longer. Dr Wesenberg-Lund some years ago formulated a theory that many plankton organisms changed their form in correspondence with the changes of temperature throughout the seasons. It was supposed that animals which in winter were able to maintain their position in the water with comparative ease would be liable to sink when the water reached a higher temperature, in consequence of the lower specific gravity of the water, unless modified so as to offer greater resistance to the downward movement through the water. But as the difference of specific gravity produced by the change in temperature would be very small, it was afterwards suggested by Ostwald that the changes of form were necessitated in a much greater degree by the varying viscosity of the water at different temperatures, and this view has been accepted by Dr Wesenberg-Lund.

It has not been possible to throw any light on this subject from the study of the Scottish lochs. There were in different lochs all the different forms of *Asplanchna*, *Daphnia*, *Bosmina*, etc., which are supposed to be the seasonal forms, and especially there was an extreme range of forms of *Ceratium hirundinella*, but in the only lochs examined throughout the year such change appeared to be exceedingly small.

Bosmina longispina was found in Loch Morar all the year round. In Loch Ness, *Daphnia* having rounded head, and *Daphnia* more or less galeate, were found all the year round. These lochs are among the largest lochs, and the annual range of temperature is very low. It may be that smaller lochs would give more definite results.[1]

The Littoral Region

The littoral region is the most populous part of a lake. The existence of a rooted chlorophyllaceous vegetation is only possible there, and this in turn supports a rich littoral fauna which otherwise could not exist. The moderate temperature of the open water of lakes is unfavourable to the growth of many forms of life, but the weedy margins, becoming heated in warm weather, favour the growth of many forms which are most at home in ponds. As there are no peculiar abyssal species, and as most of the true plankton species may be taken even among the weeds, the littoral region, well studied, gives an epitome of all the life of the lake.

The species inhabiting the littoral region need not, then, be detailed. The whole "Census of Species" forming the second part of this paper may be taken as equivalent to the littoral fauna and flora. As, however, the number of plankton species is small, and that of abyssal species still smaller, it follows that the majority of the species are confined to the littoral.

Insect larvæ of many kinds are found under stones or among weeds, only *Chironomus* being commonly found in the plankton or the mud. The great majority of the Cladocera, and the Copepods of the genus *Cyclops* and the family Harpacticidæ, are only found in this region. The Water-Mites only occasionally stray into the plankton. Nearly all the Rotifers, all the Gastrotricha and Tardigrada, exist only in this region. The Mollusca, except for the one *Pisidium* and a stray *Limnæa*, are only found here. The Rhizopods are all found in the littoral region, but nearly all are supposed to extend into the abyssal. The Chlorophyceæ are in favourable localities more abundant in the plankton, yet the majority of the species are littoral.

The littoral region has a mixed population. All lacustrine animals and plants are aquatic in the sense that they can only perform all their functions when surrounded by (at least a film of) water. Yet is it true that perfectly aquatic species form only one section of the community, and that another large section consists of animals and plants called terrestrial. One group of such species is the so-called semi-aquatic plants, some of which can live permanently

[1] See paper by J. Hewitt, p. 335.

immersed in water, but can live equally well on land if their roots can have sufficient moisture. Another group of rather different nature contains animals which live among moss. They are only functional when surrounded by water, yet they do not die (or need not) when their habitat dries up. These animals are in various ways protected against desiccation, and though they are only active when moist, they can survive droughts. Most of these animals are so completely adapted for this intermittent life (they pass through a resurrection at every shower of rain) that they are often unable to survive prolonged immersion if the water becomes in the least stagnant. The water of the larger lakes remains so fresh and well-aerated that such animals, casually introduced, it may be, live well and appear often to be permanently established in lakes. All but one or two species of the Bdelloid Rotifers and Tardigrada, of which orders there are altogether nearly 100 species in the Scottish lakes, belong to this class of terrestrial animals.

Only the shallow lochs, and sheltered bays in the larger lochs, have the marginal vegetation which supports the rich microfauna and microflora. The exposed shores are generally bare and stony, and perfectly devoid of higher vegetation. The stones are usually covered with a coating of slime, which is shown by the microscope to consist of Diatoms. When the lochs fall lowest, usually about July or August, the dried Diatoms form a white zone. It is the only instance of Diatoms becoming conspicuous in the lakes, though rarely *Asterionella* or *Tabellaria* take a share in colouring the water.

The Abyssal Fauna

The abyssal fauna is very scanty, and, so far as the observations go, very uniform in different lochs. The data available are, however, insufficient. There is no abyssal flora.

It is necessary to define the term *abyssal*, as here used, and to make comparison with the values given to the term elsewhere. Forel defines the abyssal region in the Lake of Geneva as beginning at about 100 feet, or immediately beyond the limit of chlorophyllaceous vegetation. He divides it into three parts: (1) the *superior zone*, down to about 200 feet, or the limit of actinic action in summer; (2) the *inferior zone*, from about 200 feet to the edge of the central plain; (3) the *zone of the central plain*. In this abyssal region, approaching so near the surface and the shore, there is a considerable flora, consisting almost entirely of lower Algæ, chiefly Diatoms, but including one Moss. The fauna comprises 79 species, established or erratic, the great majority of which are not peculiar to this region; but a certain proportion of species, as indicated by their specific names, are supposed to be peculiar to the abyssal region of lakes, or even of this particular lake. This number is given by Forel,[1] but Dr Penard has since greatly extended the number of abyssal Rhizopods, whatever may have been done in other classes.

In Scotland, abyssal life can only be spoken of with any confidence in the case of Loch Ness. The dredgings in Loch Morar, during the first year of the Survey, all failed, no doubt through lack of experience with the apparatus. Other lochs in which the dredge was used are not deep enough to be comparable with Loch Ness, though there was a similar fauna. Forel's definition of the abyssal region cannot be mechanically applied to Loch Ness. The central plain, though it exists in the principal lakes having the U-shaped cross-section which is supposed to indicate erosion by glaciers, is too limited in extent to be distinguished from the sloping sides, in biological studies at any rate. The steeply sloping sides of the Scottish lakes may account for an important difference in the distribution of life in them. It has been found that a large proportion of the littoral species may in Loch Ness extend to a depth of about 300 feet, so that, if we gave the littoral and abyssal regions the same limits as in the Lake of Geneva, we would have a more extensive abyssal fauna than in that lake; yet this fauna would have no peculiarities whatever entitling it to be called abyssal, but would be merely an extension of the littoral fauna.

It is necessary to have a definition of *abyssal* which will fit the peculiar conditions of the Scottish lochs. The term is here used, then, to indicate those species of animals (and plants, if there were any) which are so well established in or on the muds of the bottoms of the lakes that they are generally distributed over the mud, and likely to be found in any part examined. Thus defined, a well-marked association of animals appears, the permanent inhabitants of these muds. They occupy the central plain, if you will, but none of them are peculiar to it. They all extend into the littoral region, from which I suppose them to be derived. The region is defined by one negative character, the absence of all other species.

The depth at which the abyssal region begins varies in different lochs. In Loch Ness the abyssal association of species is fairly pure at depths of over 300 feet, a few littoral species being casual at greater depths. In Loch Earn the same association is found almost as pure at 200 feet. In St Mary's Loch it is found at 100 feet, but with a larger proportion of casual species.

The small abyssal association comprises:—

[1] *Le Léman*, t. iii. p. 242, 1904.

1 Mollusc.— *Pisidium pusillum* (Gmel.).
3 Crustacea.—*Cyclops viridis*, Jurine.
Candona candida (Müll.).
Cypria ophthalmica, Jurine.
3 Worms.— *Stylodrilus Gabreteæ*, Vejd.
Oligochæte, not determined.
Automolos morgiensis (Du Plessis).
1 Insect.— *Chironomus* (larva).
Infusoria.— Several, ectoparasites on *Pisidium* and *Cyclops*, not determined.

Of casual occurrence at great depths are:—

A brown species of *Hydra*, Loch Ness, 500–600 feet (J. Hewitt).
Limnæa peregra (Müll.), Loch Ness, 400 feet.
Proales daphnicola, Thompson, Loch Ness, 500 feet.
Lynceus affinis, Leydig, Loch Ness, 500 feet.

At depths of from 250 to 300 feet about 40 species were found, excluding Rhizopods:—Crustacea, 14 species; Rotifera, 16 species; Gastrotricha, 2 species; Tardigrada, 2 species; Infusoria, several species; Insect larvæ, Mites, Worms, etc. These records were obtained from one or two dredgings only, and the list could doubtless be greatly extended.

Of Rhizopods, the most numerous group in the abyssal collections, practically all the species known in the lochs have been recorded for depths of 300 feet and more. These records are not satisfactory, as many of them are founded on dead shells which may belong to species not capable of living at those depths.

Supposed Peculiar Abyssal Forms.—Though I have made the general statement that no peculiar abyssal species have yet been found in the Scottish lochs, some of the workers at special groups have suggested that certain abyssal examples are more or less peculiar.

Automolos morgiensis (Du Plessis).—Mr Martin says that examples dredged at 500 feet in Loch Tay were without eyes. He does not suggest making a distinct variety or species on this account. In animals which have mere pigment spots as (so-called) eyes, it is not difficult to understand how, after living for many generations beyond the influence of light, the eye-spots might disappear. Though they can hardly be regarded as organs of vision, they doubtless function in relation to light. It is otherwise with the more highly developed eyes of *Cyclops viridis*, one of the most constant abyssal forms down to 750 feet. It appears to breed in the abyssal region—at least females carrying eggs are continually found. When brought to the surface from 700 feet these creatures, which may be presumed never to have seen the light before, give every sign that they can make good use of their eyes. They grovel down among the mud, apparently seeking shelter, and they prove, by the lively way in which they dodge the threatening pipette, that they possess good, serviceable eyes.

Stylodrilus Gabreteæ, Vejd.—According to Martin, this species is general at depths of over 100 feet, and is sporadic in its occurrence in shallower water. In my experience both the abyssal Oligochætes, of which *Stylodrilus* is one, are frequent at much less than 100 feet, but this is the nearest approach to a species limited to the abyssal region.

Rhizopods.—It is among Rhizopods that the largest suggested abyssal element is found, and the evidence for it is sufficiently slender. Dr Penard, who has found so many abyssal Rhizopods in the Lake of Geneva, has been good enough to examine collections from Loch Ness. Admitting that the great majority of the species found belong to the habitual land fauna, especially to that of bogs, he claims that some half a dozen forms, *mainly varieties*, are such as he has found to be characteristic of deep lakes. Elsewhere I have given reasons for differing from Dr Penard's conclusions on this point.[1] It seems to me unsafe, in dealing with the most plastic group of the Protozoa, to regard as peculiar species examples found in peculiar habitats, which only differ minutely in the form of external shells. Such forms might be produced by the peculiar conditions of the habitat on the individual during growth, and might not indicate established varieties at all. Be that as it may, Dr Penard agrees that the evidence is insufficient to warrant any definite conclusions.

Physical Conditions in the Abyssal Region.—The most important physical conditions affecting the animals in the abyssal region of the lochs are, *first*, the uniform temperature, and *second*, the absence of light. The pressure cannot be considered important to organisms filled with watery fluid of almost the same specific gravity as water; and, as a matter of fact, animals brought from a depth of 750 feet to the surface seem to suffer no inconvenience, and can be kept alive for some time. Light and darkness appear also to be matters of indifference to a great many Invertebrata, though some are very sensitive to changes.

The abyssal region of the lakes which exceed 300 feet in depth possesses one of the most equable climates to be found anywhere. Any change which takes place is secular, and confined within very narrow limits. The temperature may not vary one degree over a period of years. It is the winter temperature of the whole loch. The summer heat has not time to penetrate to these depths before the

[1] "Rhizopods and Heliozoa of Loch Ness," *Proc. Roy. Soc. Edin.*, vol. xxv. p. 609, 1905.

winter cooling begins. Smaller lochs, which are affected to the bottom by the heat of summer, enjoy a similar equable climate during the greater part of the year, and the temperature of the bottom water is only raised a few degrees in summer. Only in very shallow lochs is there a greater range of temperature. Even in the deeper lakes a gale of exceptional duration may temporarily change the temperature of the abyssal region, but it will quickly return to the normal. The temperature of the bottom water of the deeper lakes is in the neighbourhood of 42°·0 Fahr.

Such a uniform and comparatively mild climate might be supposed favourable to many forms of animal life. Though climates offering extremes of temperature may produce the more robust forms of life, it is often found that regions where equable conditions prevail are occupied by many forms which desire to take life easy. Yet the abyssal region of the lakes is but sparsely peopled; only about a dozen species live there.

What determines the restriction of the abyssal population? Those animals which have become naturalised in the deep muds appear to be all indifferent to changes of temperature, light, etc., as they are found in all situations. An animal with good eyes, like *Cyclops viridis*, may deliberately choose the darkness of the muds. It appears to be of a timid disposition, and to be always trying to hide itself. If the abyssal region is mainly recruited, as there is reason to believe, by animals which have accidentally fallen or slid down the steep slopes of the lakes, then most of the littoral species might be introduced in this way. If so, why do so few survive? Are some of the abyssal conditions inimical to most species? Is the unfavourable condition the scarcity of oxygen in available form? It was formerly supposed that life at great depths, even in the sea, was impossible from this cause.

It is now known that, owing to currents set up by wind, and perhaps still more to the "internal seiche" which may originate in such currents, the water at the bottom of the lakes is less stagnant than was supposed. Matter in suspension in the water may carry down air to the bottom. Still, from all causes the renewal of the oxygen in the abyssal region must be very slow. Many of the abyssal animals are able to exist in very impure water, from which air is excluded. When an abyssal collection is tightly corked up, the different species exhibit different degrees of power to exist in these conditions. The Molluscs are most sensitive, and die at once; the Worms are most tenacious of life.

Animals having fair swimming powers, and eyes sufficiently sensitive to light, may be able to save themselves from the catastrophe of falling into the abyss. Some of the plankton Cladocera appear by their diurnal migrations to indicate great sensitiveness to minute variations of light, and the littoral species may have the same powers.

DISTRIBUTION

One of the departments of biology which it is hoped will be in some degree advanced by the labours of the Lake Survey is the study of distribution. Complex and difficult as is the investigation into the causes of the distribution of animals and plants over the globe, such as it is at the present day, vast accumulations of facts are needed before we are in a position even to tackle the problems with any hope of successful solution.

The part played by climate in bringing about the present distribution, the gradual changes of climate, the modification of species under this influence, the present and past forms of the continents and oceans, the alterations of sea-level, the facilities for transference between more or less widely separated regions, and in recent times the influence of man since commerce became universal,—all together render the problem of distribution one of the most complex and difficult, yet for that reason one of the most fascinating, studies for naturalists.

If generalisations are attempted from insufficient data, very erroneous conclusions may be made. In no branch of natural history can it be said that the materials available are adequate for the exhaustive study of distribution. It thus happens that the commonest drudgery of the local naturalist, the mere collector's work and the tabulating of species, if conscientiously and accurately done, gains an importance and interest mayhap undreamt of by the collector. The abundant records obtained by the Lake Survey, though got haphazard while other work was being done, at all seasons of the year, and without any definite plan in which the biology was considered, nevertheless present a serviceable mass of information. Each record, with its locality, is a definite fact, which can be used and assigned its proper place by special students of distribution.

The more delicate problems of distribution will not be solved by mere compilers of lists of species in different regions of the world. Each naturalist gives his own value to the terms "species" and "variety," and if every man's contribution to the structure be compiled without knowledge, the results may not justify the trouble. The valuation of the lists of species will have to be made, for each group, by men who know the whole group, and will know the values of species and variety, and the various shades of affinity within the group. While waiting for this ideal system of studying distribution, we must make our catalogues as best we may, and compare them together when made for such light as they can yield us, and for suggestions as to future work.

As to the distribution of the great majority of the 724 species recorded in the lists, it must be said that very little is known. The littoral region, where life is most abundant, has only been occasionally studied. Many of the species are only once recorded, yet there is no reason to believe them rare. The species which are cosmopolitan or generally distributed are indicated by the word "general" in the lists.

The distribution of the majority of the species will not be dealt with at all. In this place there will be studied in detail the distribution of a few species which are fairly well known, and are not of general occurrence, and some which are very local or rare. In dealing with some little-known species, such indication as is possible will be given of their world-distribution.

Zooplankton

Mollusca.—Of the two large bivalves in the lochs, *Unio Margaritifer* (L.) is the general species in the Highland lochs, and *Anodonta cygnea* (L.) is the Lowland species.

Hydrachnida.—*Lebertia tau-insignita* (Lebert). This species, discovered in the Lake of Geneva, in the abyssal region, is common in Scotland, and is not solely abyssal in this country. It was supposed to be one of those forms which found analogous conditions in the littoral region of northern lakes, and in the abyssal region of more southern lakes. Several other animals are in the same category. The recent discovery that the British species, recorded under the name of *L. tau-insignita*, is really some other species, modifies this view. All the records, therefore, require revision.

Huitfeldtia rectipes, Thor.—A northern species, inhabiting (so far as previously known) only Scandinavia. In Scotland it has only as yet been recorded for Orkney, where it was discovered in 1906. It is there the commonest species.

Tardigrada. — *Echiniscus gladiator*, Murray. — Pretty widely spread in Scotland, and not peculiarly lacustrine; it is now known from the Faroes (Sellnick), somewhere in the Pacific region (Richters), and British Columbia.

E. wendti, Richters.—Scottish and Arctic. Richters doubts if the animals in these two regions are the same.

E. spitsbergensis, Scourfield.—Scottish and Arctic. Pretty widely spread in Scotland.

Macrobiotus ambiguus, Murray.—Scottish, Swiss, and Arctic. On ground-moss and lake margins in Scotland; on a deeply submerged moss (abyssal) in the Lake of Geneva.

Crustacea.—Genus *Diaptomus*.—It is a curious fact that, although the three northern species of *Diaptomus* occur together in many districts, each is almost completely isolated, judging from the records available. There are rarely two of them in the same loch. There are over a hundred lochs in which one or other of these species is present, yet there are only nine lochs in which two or more of them were found, only two lochs in which all three were associated.

In thirty-six lochs *D. gracilis* was found in company with one of the northern species, and in only two lochs (nan Cuinne and Baddanloch, in Sutherland) were all four of the pelagic species present. A fifth British species, *D. Castor*, has only been found in ponds, but Dr Scott has seen it in a few lochs.

What are the conditions causing this isolation of species occupying the same region? Is it the physical or chemical properties of the water of the different lochs?—all can live together in some lochs. Is it climate?—the different species will occupy adjacent lochs, among the same formations of rocks, and apparently identical surroundings. Is it altitude?—*D. laciniatus*, *D. laticeps*, and *D. gracilis* range from almost sea-level to 2500 feet, at least. *D. wierzejskii* has a lower vertical range, and is more thoroughly isolated, occupying by itself extensive regions. The restriction in this case may well be climatic.

A second species, too immature to be identified, was often found in lochs; if mature individuals were found in their season, it might appear that there is more mixing of the species than is at present supposed.

Diaptomus laciniatus, Lillje.—This species has been recorded by the Lake Survey in 37 lakes—7 in Central and West Inverness; 9 in Sutherland; 6 in Ross (apart from Lewis); 13 in Lewis; 1 in the Clyde basin (Loch Lomond); and 1 in Ayrshire (Loch Doon).

As it has a limited season, having been observed only during four months (from June to October), its range might be somewhat extended if all the lochs could be examined at the right season. As the records stand, they show an essentially Western and Highland species, the only locality in the south of Scotland being a truly alpine lake. The most easterly records of the Lake Survey are in Sutherland, though Mr R. M. Clark found it a little farther east, in the western corner of Aberdeen, an alpine district. It ranges in altitude from lochs just above sea-level (Loch Shiel, etc.) to 2500 feet in Inverness. Considering that it is most abundant in Lewis, it is curious that there are no records for Uist, nor for Orkney and Shetland.

It is one of the species, according to Dr Wesenberg-Lund, belonging to Ekman's "boreo sub-glacial" region, and outside of Scotland is known in Scandinavia, North Russia, and the alpine lakes of Switzerland.

D. wierzejskii, Richard.—The Lake Survey has 30 records of the occurrence of this species. It has a much more restricted range than *D. laciniatus*, and is mainly confined to the extreme northern and western fringe of the country. There are 3 records for Sutherland; 1 for Caithness; 2 for Lewis; 3 for Uist; 20 for Shetland; and 1 for Ross (strange to say, in the extreme east). The western islands were visited when the *Diaptomus* was in most lochs too young to be identified, and Dr Scott's records show that it is much commoner in the Outer Hebrides—he notes it in 8 lochs in the small island of Barra alone,—and in Shetland he gives many additional localities. Dr Scott found it in Mull, which is its southern limit in Scotland; its eastern limit on the mainland is St John's Loch, in Caithness. It is the common, and almost the only, species in Shetland, but has not been noted in Orkney. It is the only species found in Uist, except the closely related *D. laticeps*, only distinguishable when fully mature.

Its general distribution, so far as known, is apparently discontinuous: it occurs in Spain, Germany, and North Russia. In altitude it is not known to ascend so high as *D. laciniatus*, the highest locality from which I have noted it being Loch Maol a' Choire, in Sutherland, 900 feet above sea-level. A great many of the lochs where it occurs are very little above sea-level.

D. laticeps, Sars.—This is the commonest and most generally distributed of the northern species of *Diaptomus*. Though mainly a Highland species, it is recorded from a reservoir near Edinburgh. The Lake Survey has 46 records for it—5 for Perthshire; 12 for Inverness; 7 for Sutherland; 2 for Caithness; 3 for Orkney; 1 for Shetland; 1 for Ross-shire; 10 for Lewis; 3 for Uist; 1 for Argyll, and 1 for Edinburgh. It is found at all elevations, from the slightly tidal Loch of Harray, in Orkney, to about 2500 feet in Perthshire. Out of Britain I only know the species as Scandinavian.

D. gracilis, Sars.—The commonest species in Scotland, as in Europe generally, its distribution only calls for remark because of the apparent total absence from the Shetland Isles and North Uist. In the Orkneys it has been noted only in two lochs.

On the mainland it is almost universal, but is occasionally replaced by one of the three northern species (*D. laciniatus*, *D. laticeps*, or *D. wierzejskii*). Usually it accompanies those species where they occur. In only one district, N.W. Sutherland, did it appear to be absent from most of the lochs.

Asellus and *Gammarus*.—Though both these Crustacea, the largest in the lochs, are common, they are seldom found both in the same loch.

Mysis.—The *Mysis* in the lochs is apparently a migrant, not a relict, and its scattered distribution and rarity are probably determined by the scarcity of suitably situated lochs. Only one of the lochs where it occurred is tidal (Loch Wester); the others are little above sea-level.

Latona setifera (Müll.).—There are only 12 records of this beautiful animal—1 loch in Ross (Loch Ussie); 4 in Inverness (Lochs Ness, Oich, Laggan, and na h-Earba); 6 in Perth (Lochs Kennard, Sròn Smeur, Tilt, na Bì, Rannoch, and Laidon); and 1 in Kirkcudbright (Loch Trool). Dr Scott's records show a wider range, giving extra localities in Perth and Inverness, and many records for the Shetland Islands.

Bosmina longirostris, Müll., and *B. obtusirostris*, Sars.—The Arctic species, *B. obtusirostris*, is all but universal in Scotland, being absent only from some small lowland districts, chiefly in the south-east. *B. longirostris* occupies these lowland districts, usually in the variety *cornuta*. There is reason to believe that *B. longirostris* often exists along with *B. obtusirostris* in the Highland region, the former as a littoral, the latter as a plankton form.

B. coregoni, Baird, is only known from two lochs—Loch Heilen in the extreme north (Caithness), and Castle Loch in the extreme south (Dumfries).

Ophryoxus gracilis, Sars.—Only recently detected in Britain by Mr Scourfield, and only known in two of the lochs of the Caledonian Canal (Lochs Ness and Lochy), and in the Canal between these lochs. In Europe it is purely a northern species, only found in countries bordering on the Arctic Ocean. In the United States it is found farther south, in Minnesota and Wisconsin.

Ilyocryptus acutifrons, Sars.—Known in two far-separated districts in Britain, Sutherland and Norfolk.

Candona elongata, Brady and Norman.—The only known stations for this species, Lough Neagh in Ireland, and Loch Dùn na Seilcheig, near Inverness, Scotland, offer a puzzle in distribution, but it cannot be said that the intervening region has been sufficiently well searched to demonstrate their real isolation.

Rotifera.—*Conochilus volvox*, Ehr., and *C. unicornis*, Rouss.—Both are generally distributed and are sometimes found together, though rarely. The dominant species in Scotland is *C. unicornis*.

Microdina paradoxa, Murray.—Common among the marginal vegetation of pure lochs in Scotland, and also in streams; it is as yet unknown elsewhere except in the Lake of Geneva, and in New Zealand.

Philodina hamata, Murray, *P. laticeps*, Murray, and *P. laticornis*, Murray.—Though only as yet recorded from Scotland, these species are likely to be as widely diffused as the *Gammarus* with which they are found. *P. hamata* is only known in two lochs, far apart (Loch Tay and St Mary's Loch), and *P. laticornis* in two lochs of the Caledonian Canal (Lochs Ness and Lochy). *P. laticeps* is commoner.

Callidina angusticollis, Murray.—One of the most thoroughly cosmopolitan of all animals; it is found in both polar regions, the tropics, and in all the continents.

C. longiceps, Murray.—Very rare in Scotland, being only known in one loch; this curious species has been found in two widely separated parts of Africa, Uganda and Cape Colony, and in Fiji and Hawaii.

C. crucicornis, Murray.—Apparently very rare and local; only known in two places in Scotland, Loch Rannoch and Fort Augustus (abundant in one small bog hole at the latter place); also W. Ireland.

C. armata, Murray.—Apparently rare, only known till recently from the Caledonian Canal and lochs on it; its range has been extended to Orkney by its discovery in the Loch of Harray.

Rotifer trisecatus, Weber.—Not very rare in ponds, though rare in lakes.

Polyarthra euryptera, Wier.—Though exact details of its distribution are not yet available, it is known that this species has a pretty wide range, especially in the north and west.

Triarthra longiseta, Ehr.—Pretty generally distributed, but local. It may be that this species and *Floscularia pelagica* have a limited season, which might account for their seeming comparative rarity.

Albertia bernardi, Hlava.—I am informed by Herr Hlava that the species of *Albertia* recorded by me[1] as *A. intrusor*, Gosse, is really *A. bernardi*, and I correct my mistake accordingly. I know not whether the true *intrusor* also occurs in *Stylaria* in this country. I only know one species.

Notommata pumila, Rousselet.—This appears to be really a rare species. The conspicuous characters of the toes make it unlikely that it would be overlooked.

Proales daphnicola, Thompson.—The single occurrence, on a worm at a depth of 500 feet in Loch Ness, of this species, usually found on Crustacea, is one of the curious, isolated facts for which there is yet no explanation.

Furcularia reinhardti, Ehr.—Frequent in the plankton of lochs, also in the littoral region, in streams, and in the sea; the species varies so greatly in size that there is some doubt as to its identity in all cases.

Arthroglena lutkeni, Berg.—This species, found at the Loch of Swannay in Orkney, was not seen alive, but was identified by the characteristic toes.

Dinocharis similis, Stenroos.—Though only yet seen in Loch Ness, it is likely that it has been confused with *D. tetractis*, which is supposed to be extremely variable.

Polychætus collinsi, Gosse, and *P. subquadratus*, Perty, though littoral forms, are not infrequently found in the plankton, and on one

[1] *Trans. Roy. Soc. Edin.*, vol. xlv. p. 178, 1906.

or two occasions they have been abundant in the plankton of the smaller lochs.

Cathypna ligona, Dunlop.—This species appears to be rare or extremely local. It is such a peculiar form that it is little likely to be overlooked. Where it occurs it is often abundant.

Colurus tesselatus, Glascott.—Another species which, though small, is unmistakable, and apparently rare.

Noteus quadricornis, Ehr.—Usually found in very shallow lochs. It was, however, pretty abundant in the plankton of Talla Reservoir, in the deepest part, within a year of the filling of the reservoir.

Eretmia cubeutes, Gosse.—Mr Rousselet, from the side of the Rotifera, considers that the Rotifer *Eretmia* is simply some species occupying a Rhizopod shell; Dr Penard, from the side of the Rhizopods, comes to the same conclusion. It would be interesting to know what Rotifer does this, and if the combination is habitual. From the little I have seen of the dead Rotifers in the shells, I am inclined to think that it is some species which normally adopts the hermit-crab mode of living.

Gastropus stylifer, Imhof.—After the half-dozen species universally distributed in the plankton, one of the commonest species is *G. stylifer*. It is very generally distributed; its brilliant colouring causes it readily to catch the eye when present; it has been noted in more than 70 lochs, yet it appears to be to some extent local.

Phytoplankton

Phanerogamia.—*Stratiotes aloides*, L.—The Water-Soldier was only observed in the little Loch Fithie, near Forfar, which it almost filled in its season, the plants being very large.

Elodea canadensis, Miche.—This introduced plant is a pest in many lowland lochs.

Muscinæ.—*Hypnum scorpioides*, L.—Though *Fontinalis* is the commonest littoral moss, *H. scorpioides* is more frequently submerged to a considerable depth. In lake-bottoms it is considerably modified from the terrestrial form, and is pronounced by Mr H. N. Dixon and M. Cardot to be very near to var. *miquelonense*, Ren. and Card. The specimens submitted to those specialists were from Loch Ruthven. A similar form from the Peerie Water, in Orkney, is considered by Mr Dixon to be an undescribed variety.

Florideæ.—*Sacheria* (= *Lemanea*).—This curious plant, which usually affects running water, has been twice seen in Scottish lochs—abundantly at the overflow of Loch Vennachar, and sparingly in Loch Ness, on submerged rocks at Port Clair.

Desmids.—The distribution of the Desmids will not be traced in detail, except for a few species. Desmids are abundant in the lochs of the Highland region, and are of very little importance in the Lowland region. As there are few lochs in the Lowland region, Desmids are common in the majority of the lochs. In the Highland region a few species, usually small and inconspicuous, are generally distributed. A much larger number, including the majority of the large and beautiful plankton species, are greatly restricted in their range. They are in the greatest abundance in the north, in Sutherland and Lewis. Messrs West declare the plankton of Loch Fadagoa in Lewis to be the richest they ever examined, and Desmids are especially abundant in it. Several lochs in Sutherland are but little inferior to Loch Fadagoa. These Desmids are fairly represented here and there in lochs of the west coast, and some alpine lochs of the central counties, Perth and Inverness, have a rich Desmid flora. In Ayrshire a few alpine lochs recall the abundance of Sutherland.

Micrasterias murrayi, West.—Only known as yet in two widely separated localities, Sutherland and Ayrshire. The type is in Loch an Ruathair, in Sutherland; a triquetrous variety in Lochs Doon and Bogton, Ayrshire, two lochs on the same river. The species appears to be very near to, and probably derived from, *M. papillifera*, Bréb.

M. mahabuleshwarensis, Hobson, var. *wallichii* (Grun.).—The distribution of this variety (the type of the species not being found in Britain) is very curious. It is in three lochs of the Tay basin, (Lochs Bhac, nan Eun, and Shechernich), three in E. Sutherland (Lochs an Ruathair, nan Cuinne, and Leum a' Chlamhain), and two in Shetland (Lochs Littlester and Burraland).

M. radiata, Hass = *M. furcata*, Ralfs.—This species is almost as local as *M. mahabuleshwarensis*. It occurs in a few lochs in Perth and Inverness, is generally distributed all over Sutherland, though only in a small proportion of the lochs, and extends into Lewis (Loch Fadagoa) and Caithness.

M. conferta, Lund, var. *hamata*, Wolle.—Fairly common in the north, especially in Sutherland.

M. apiculata (Ehr.), var. *fimbriata* (Ralfs).—Common in the north.

M. brachyptera, Lund.—Loch Ness; Sutherland; and Lewis.

M. verrucosa, Bissett.—Though Roy and Bissett have recorded this species from many localities in the east, it only once occurred in Lake Survey collections, in Loch Ness.

Xanthidium subhastiferum, West, var. *Murrayi*, West. This remarkable Desmid, which should be regarded as a form rather than as a variety, is only known from Loch Morar, where it is very abundant. Though its form is altogether peculiar, Mr W. West, on first inspecting a drawing of it, suspected its affinity to *X. subhastiferum*, an opinion since justified by the finding of many examples having one semicell of the type and the other of the variety. It appears like an incipient species; yet, considering its abundance in Loch Morar, and the facilities for dispersal into other lochs immediately adjoining, its restriction to this loch is remarkable. The continual occurrence of semicells of the type and variety in the same example shows how little fixity the form has. All this suggests the query whether the physical properties of the water of a loch may not give rise directly to peculiarities of species. The absence of the family Daphnidæ from Loch Morar is another unexplained fact in distribution.

Palmellaceæ.—*Tetraëdron limneticum*, Borge.—Confined to the extreme north of the mainland; only known from Loch an Ruathair in Sutherland, and Lochs Shurrery and More in Caithness: a Scandinavian species.

Diatoms.—*Asterionella gracillima*, Heib., and *A. formosa*, Hass.—Although *Asterionella* is one of the commonest plankton organisms, the two species are rarely found together. Messrs West doubt whether the two species, which differ chiefly in the relative slenderness of the cells, are really distinct, and the fact that they are not to any extent mixed in the lochs gives support to this theory. Though both are widely distributed, *A. gracillima* appears to be more a Highland and western form, *A. formosa* more Lowland. In some small Lowland lochs *A. formosa* is greatly reduced in size, and the colonies are cruciform, having only four cells.

Fragilaria crotonensis, A. M. Edw., var. *contorta*, West.—The type of the species is common in the north and west, but the strikingly beautiful variety is of much more restricted range. It is only known in Sutherland, where it was first obtained in some small lochs on the west coast. Afterwards it was found in three lochs of the Helmsdale basin, in E. Sutherland, Lochs nan Cuinne, Baddanloch, and an Ruathair. It was from plankton from Loch an Ruathair sent to Mr West that the variety was described.

The filaments are short, apparently of a definite and uniform length, and are very strongly twisted, so that each looks like a pair of fans joined together.

Tabellaria fenestrata (Lyngb.) and *T. flocculosa* (Roth.).—Both species are usually present together. *T. fenestrata* is very often in spiral colonies (var. *asterionelloides*). The stellate form of *T. flocculosa* is, on the other hand, very rare, and has only been seen in one or two lochs.

ON THE BEARING OF THE BIOLOGICAL EVIDENCE AS TO THE ORIGIN AND AGE OF THE SCOTTISH LOCHS

We cannot hope to derive from the study of the biology any positive information as to the mode of origin and possible age of our lakes. We look to geology for approximate answers to such questions. When geology has pronounced upon them, we may examine the biology in its bearing upon the supposed origin and age, and seek confirmation or the reverse.

If the lakes are excessively ancient (geologically speaking), we may reasonably expect a fauna and flora rich in peculiar forms. If they are but of yesterday, we may expect a fauna and flora easily derived from surrounding regions. If it is admitted that there have been several glacial periods, separated by long intervals, it may be that some of the Scottish lakes are of respectable antiquity, considered merely as lakes or depressions in valleys. As, however, each glacial period would interrupt the life of the lake, destroying the individuals and annihilating any peculiar species which might have originated in it, it follows that, as a biological entity, each lake dates only from the termination of the last glacial period affecting the region where it is found. Again, if there has been, since the last glacial epoch, sufficient elevation of the land to convert depressions of the sea-bottom into fresh-water lakes, such lakes, in respect of the investigation into fresh-water life, date only from the time when fresh water replaced salt in the basin. If any lakes have originated in the latter way, there might be found survivors of the marine fauna which formerly occupied the basin.

Comparison with other European Lakes

Various European lakes possess what are supposed to be survivals of a marine fauna or a peculiar fresh-water abyssal fauna.

Lake of Geneva.—As the most fully studied of European lakes, we will consider that lake most carefully. Professor Forel enumerates 79 species. Excluding vertebrata, which we cannot compare with his, there are 65 species of abyssal animals. As his abyssal region begins very near the surface, and the majority of the species are not peculiar to it, we are only concerned here with the small number of peculiar species. On the most conservative estimate, about 20 of those are peculiar species, discovered for the first time in the Lake of Geneva, many of them restricted to that lake, and supposed to be specially adapted to abyssal conditions. They are chiefly Crustacea, Mollusca, and Worms.

In dealing with these facts there are many reasons for being cautious. The different groups are treated by different men, each with his own estimate of specific values, and in some groups the specific differences separating the abyssal species seem to be exceedingly minute. The Lake of Geneva has been more carefully studied than most other lakes, and we may expect it to appear that many of the species are really widely diffused. This is already known of several species. Dr Penard, in a quite recent work,[1] states that he has found 48 Sarcodina, characteristic of great lakes, in the Lake of Geneva. 26 species are very well marked, and not readily traceable to species of the plain; 14 species, while quite distinct, can be easily traced to their origin; 8 are varieties merely. The minutest differences help in understanding the origin of species, when the relative values of the different species are discriminated so carefully as in that important work of Dr Penard.

Making due discount for species of doubtful value, there are in the Lake of Geneva a number of very distinct species, which seem specially adapted for abyssal conditions. Professor Forel concludes[2] that the abyssal fauna originated from the littoral, by migration and adaptation. There is no suggestion that any of the abyssal species of the Lake of Geneva are of marine origin.

It can now be stated that a number of animals, which were supposed to be confined to the abyssal region of the Lake of Geneva, exist elsewhere, and that they are not exclusively abyssal. Several of Dr Penard's abyssal Rhizopods are found in shallow waters and even in peat-bogs in Scotland. *Lebertia tau-insignita* has been frequently recorded for Scotland, and from shallow waters as well as deep. It has quite recently been ascertained, however, that some of the Scottish specimens recorded under this name were really another species, and doubt is thus thrown on all the records.

Macrobiotus ambiguus, a Tardigrade recently discovered in Scotland and Spitsbergen, is not in these countries an abyssal species, or even especially lacustrine. It has been found among land moss, and in shallow waters. In the Lake of Geneva its eggs were found in great numbers on the submerged *Thamnium lemani*, obtained at a depth of 200 feet by Professor Forel in 1906. As the identification of Tardigrada from the eggs alone is rather uncertain, it was with great satisfaction that I observed the young issue from some of the Swiss eggs, and found that they agreed perfectly with the Scottish and Arctic examples. This species was not found among *Fontinalis* from the margin of the lake. A plausible explanation of such distribution suggests itself. It might be supposed that an Arctic species would only find congenial temperature conditions by descend-

[1] *Les Sarcodinés des Grands Lacs*, Geneva, 1905.

[2] *Le Léman*, t. iii. p. 294, 1904.

ing to the cool depths of the southern lake; but such an explanation is discounted by the animal occurring in Scotland, and especially in the northern islands, where the climate is so mild.

Other Swiss Lakes.—Later investigations by Penard, Zschokke, and others have shown that some at least of the species supposed to be exclusively abyssal are present in other Swiss lakes. *Asellus foreli*, *Niphargus foreli*, *Macrorhynchus lemani*, *Plagiostoma lemani*, and many of the Rhizopods, are found in some or in many other lakes. Zschokke, in a quite recent work[1] which I have been unable to consult, enumerates 100 species which he found in the Lake of Lucerne at depths of 170 metres and more. He divides the species into two classes: (*a*) littoral forms, which have migrated downwards; and (*b*) genuine abyssal forms, which represent relicts of a stenothermal post-glacial fauna.

Forel contends that true abyssal species are completely isolated in each lake, and cannot be disseminated from one lake to another. Cross-breeding between species in analogous situations in different lakes will thus be completely precluded. This view appears to be the only one tenable, in the present state of knowledge. Abyssal species might have their distribution provided for by means of floating eggs, etc.; but there has been no suggestion that such means of dissemination actually exist. Yet there are peculiar abyssal species identical in different lakes, completely isolated from one another.

Forel argues consistently that in each lake the abyssal forms have originated independently, *in situ*, and he traces each to the parent form among littoral species. If the independent origin in each lake is not admitted, an alternative view is that the abyssal forms are survivals of a time when conditions were different, when all the lakes where they are found were united, or when the climate was such that these species would find their suitable environment in the littoral region. In either case migration would be possible. The abyssal fauna would in this view be, like the marine relict fauna, a relict fauna, but surviving from earlier fresh-water conditions.

The study of the Scottish lakes, where the amount of abyssal peculiarity is very small, favours Forel's view that the abyssal fauna originated in each case *in situ*. He shows that the amount of modification of the abyssal species is very small, and that they should rank, from the morphological point of view, as simple varieties. The only species apparently greatly modified in adaptation to abyssal conditions, the blind Crustacea, *Asellus* and *Niphargus*, are derived from the subterranean blind species, and but slightly modified.

The abyssal species in different lakes are, then, only parallel modifi-

[1] *Arch. Hydrobiol. Planctonkunde*, ii., 1906, Heft 1, pp. 1–8 (quoted in *Journ. Roy. Micr. Soc.*, 1907, p. 296).

cations, produced by the peculiar environment. They may be rather forms or states of the littoral species than varieties or distinct species.

From the point of view of development the Lake of Geneva is very young. The amount of modification produced by the abyssal conditions is inconsiderable. If the lake is ancient, measured by ordinary standards of time, the modification of species by the peculiar environment must be very slow.

The Danish Lakes.—The Danish lakes, investigated by Dr C. Wesenberg-Lund, are all shallow, and a peculiar abyssal fauna is hardly to be expected. Dr Lund, in a very instructive paper,[1] notes six species of marine origin, whether migrants or relicts, in the Danish lakes. The three free Crustacea among them, *Mysis relicta*, *Ponteporeia affinis*, and *Pallasiella quadrispinosa*, are the common relict animals in a great many countries.

Other Lakes.—In the paper above cited Dr Lund gives an account of the occurrence of these relict species in Sweden, Norway, Russia, Germany, Britain, and North America.

The Scottish Lakes.—*Abyssal Fauna.*—Although in the Scottish lakes about 20 species of animals are found thoroughly established in the abyssal region, none of the peculiarly abyssal forms of the Lake of Geneva have been found, except *Automolos morgiensis* and some half-dozen varieties of Rhizopods. *Automolos morgiensis* is now known to be widely diffused over Central Europe. In the Lake of Geneva as in Loch Ness it exists in the littoral region as well as in the abyssal. Its derivation from the littoral is thus easy, and migration from one lake to another is rendered possible, so that it is not necessary to postulate an independent development in each lake.

It would be premature to assert that the peculiar abyssal fauna is absent from the Scottish lochs. The observations are very few, except in Loch Ness. The collections have not been seen by specialists in abyssal faunas, except in the case of the Rhizopods worked up by Dr Penard, who did note some few forms which he considers peculiar to deep lakes. Possibly if the Mollusca, Crustacea, and Worms were seen by naturalists acquainted with the fauna of deep lakes, they might detect peculiarities of form among the abyssal examples.

It can only be said definitely that Loch Ness has been examined so frequently by different naturalists with various apparatus that it is unlikely that any conspicuous peculiar forms have been overlooked. If Loch Ness fairly represents the Scottish lochs, there is an exceedingly meagre abyssal fauna, without a single peculiar species. All the species are clearly derivable from littoral species, and indeed the

[1] "Sur l'existence d'une Faune Relicte dans le lac de Furesö," *Bull. Acad. Roy. des Sci. et des Lettres de Danemark*, 1902.

abyssal examples do not as a rule differ perceptibly from littoral examples.

What bearing have these facts upon the age of Loch Ness relatively to the Lake of Geneva? The poverty in abyssal species and even varieties does suggest that there has been a much longer time for the modification of species in the Lake of Geneva than in Loch Ness. Slight though the modification in the Lake of Geneva may be, it is still less, or practically nil, in Loch Ness.

There is one factor in the development of species which must be considered in comparing these lakes. In the development of varieties, and eventually of species, isolation plays an important part. When a species migrates into a new environment, selection will at once begin to adapt the species to the environment; but if there is no degree of isolation, cross-breeding will prevent or retard the change. One would expect the rapidity of change to depend to a large extent on the degree of isolation. In a great lake like the Lake of Geneva the first migrants to the central plain might remain long without recruits from the littoral. Cross-breeding with more recent migrants might be so infrequent as not to retard the action of selection. There might thus originate in the central parts of the lake races better adapted to the abyssal conditions, which might then gradually occupy all the region for which they were specially fitted.

Whether the actual history of the abyssal fauna of the Lake of Geneva in any way corresponds with that theory, in Scotland such an origin would be unlikely. The central plain of the lakes is never extensive. The steep sides bringing numbers of involuntary migrants, these could readily traverse any part of the central plain, mingling with the earlier natives. Migration from the shore might thus give rise to no peculiar forms. The facts at any rate accord with this theory.

Fauna Relicta.—None of the marine relicts, or more recent migrants, have been found in the Scottish lochs. We had on Loch Ness, Loch Lochy, etc., the benefit of the assistance of Dr Wesenberg-Lund, who was acquainted with the relict fauna in the Danish lakes, and who used the same apparatus and methods in Scotland which were successful in obtaining the relicts in Denmark. *Mysis* has been found in several lochs, but those were all very close to the sea and near sea-level, so that migration would be easy. Those examples which have been determined were all *M. vulgaris*, never *M. relicta*.

Origin of the Scottish Lacustrine Fauna and Flora.—The derivation of the whole lacustrine population presents no difficulty, since it has been possible to trace the abyssal fauna directly to the littoral, without even perceptible modifications. The plankton is a mingling of the common European species with Arctic species. The cosmopolitan species may enter the lochs by ordinary migration. It is probable that if the plankton could be annihilated it would be replaced by ordinary migration within a few years. Eggs and spores of many of the species can be dried up without injury, and may be carried through the air as dust from one lake to another. Others which could not bear desiccation might be conveyed among mud adhering to the feet of aquatic birds, and in various other ways. So great is the facility with which plankton species can be transferred from one lake to another, that the chief difficulty has been to account for the restricted distribution of certain species.

An experiment, which by good fortune we were able to make in Scotland, illustrates the rapidity with which plankton may find its way into a loch. A large artificial lake having been constructed, several miles in length, of considerable depth, and separated by many miles from any other lake, an examination of the water was made several times during the first year. In the course of a few months many of the cosmopolitan species found their way in, and increased till they were as numerous as in an old-established loch.

The Arctic species in the Scottish plankton might be derived from Scandinavia by ordinary migration. Considering the great extent of sea which now separates the two countries, the probability of direct migration is slight, and a more reasonable theory is that they are survivors from a period when Arctic conditions prevailed over a great part of Europe.

The littoral fauna and flora may be equally readily disseminated, as they are more constantly liable to desiccation than the plankton, and more of the species may be protected against annihilation by the production of resting eggs or spores. A large proportion of the littoral population is not exclusively aquatic, but belongs to that extensive family supported by mosses and similar plants, the members of which resume their activity every time the moss is moistened. Such organisms need not migrate directly from lake to lake, but may find intermediate resting-places anywhere.

Wallace, in his *Island Life*, makes a review of the biology of the British Isles, and remarks on the very small number of endemic species (the Red Grouse, one Moss, and so forth). The numerous species or varieties of Salmonidæ, restricted to certain lochs, are referred to, in relation to the question of the length of time that Great Britain has been an island. The duration of the insular character of Great Britain is quite apart from the duration of its lochs. These may be older than the island. Fresh-water lochs being isolated by as efficient a barrier as the sea would be, the existence or non-existence of the English Channel does not in any way affect them.

Summary

The facts and conclusions as to the biology of the Scottish lochs, dealt with in the preceding pages, may be briefly recapitulated.

Geographical Situation.—Biologically, Scotland occupies an intermediate position between the Central European plain and the Arctic regions. In situation Scotland lies so near the Arctic Circle, being at the latitude of Labrador and Alaska, that it might be reckoned an Arctic land. The climate is, however, so modified by the proximity of the Atlantic Ocean, with its warm currents, that it is extremely temperate, and the result is a mingling of Arctic and Southern species, the Arctic, however, predominating.

Fauna and Flora.—724 species have been identified in the Lake Survey collections, the great majority being microscopic. The fauna includes 447 species, all Invertebrata; the flora comprises 277 species. They are distributed in the various Classes, Orders, or Families in the following proportions :—

Mollusca	7	Phanerogamia	65
Hydrachnida	17	Equisetaceæ	1
Tardigrada	30	Selaginellaceæ	1
Insecta	7	Characeæ	6
Crustacea	78	Musci	18
Bryozoa	7	Hepaticæ	2
Worms	25	Florideæ	2
Rotifera	181	Chlorophyceæ	142
Gastrotricha	2	Bacillariaceæ	26
Cœlenterata	1	Myxophyceæ	10
Porifera	1	Peridineaceæ	4
Protozoa	91		
	447		277

New Species.—In the course of the work 29 previously unknown species have been found, chiefly in the neglected groups of the Tardigrada and Bdelloida (13 Tardigrada, 1 Oligochæte, 11 Bdelloida, 1 Desmid, 1 Flagellate, 2 Algæ).

New British Records.—Practically the whole of the Tardigrada (30 species), and 25 species of Rotifera (including the new species), are additions to the British fauna. Three species of Crustacea were found for the first time in Great Britain, one (*Candona elongata*) being previously known in Ireland. Many of the Sarcodina, and some Desmids and Mites, are also additions to the British lists, but the precise numbers could not be given without more sifting of literature than time permits of.

The Plankton.—There are about 30 species of animals and 80 plants of common occurrence in the plankton. 15 of the animals and 13 of the plants are generally distributed—the others are more or less local. Most of the local species are confined to the west and north of the mainland, and the islands. The chief characteristics of the plankton are the abundance of Desmids, and the predominance of Arctic species of Crustacea.

The *seasonal change* is but slight, especially in the larger lochs. Most of the Arctic species are only present in summer and autumn.

The *temperature* of the larger lochs has a very small annual range, rarely reaching 20° Fahr., and there is rarely any approach to "flowering," but such as there is may occur in winter.

A *diurnal migration* of the plankton has been noticed, the larger Crustacea coming to the surface after dark. The plankton animals are normally abundant in the larger lakes down to a depth of 200 feet and more. *Leptodora* appears to make the journey from this depth to the surface with great rapidity, as it has been found to arrive at the surface immediately after sunset.

Littoral Region.—The margins of the lakes, though usually somewhat deficient in higher vegetation, possess in favourable localities a very rich microfauna, of Tardigrada, Worms, Rotifera, Infusoria, etc., only partly worked out.

The Abyssal Region.—The muds of the deeper lakes support a very sparse population, of about a dozen species—1 Mollusc, 3 Crustacea, 3 Worms, 1 Insect, and several Infusoria. Many others are casually found in the abyssal region, and in Loch Ness upwards of 40 species of animals have been found at a depth of about 300 feet.

There are no peculiar abyssal forms in the lochs, unless a few Rhizopods found by Dr Penard be considered as such. No *relicts* of a marine fauna have yet been found in the lochs. The physical conditions characteristic of the abyssal region are total darkness, equable temperature, great pressure. The poverty of this region may be attributable to a deficit of oxygen in available form.

Origin of the Fauna and Flora.—As no relict fauna has yet been found in the lakes, there is no reason for supposing that any part of the lake-fauna has had a marine origin, or has come through the intermediary of a great inland sea or lake, such as has been postulated to explain the distribution over the great European plain. And as there is likewise no peculiar abyssal fauna, or peculiar forms at all in the lakes, the tracing of the origin of the population found in them now is comparatively simple. Ordinary migration will account for the greater part of it, and this may be extremely rapid.

The admixture of Arctic and southern forms may be accounted for by changes of climate, the Arctic species coming south during a cold period. The abyssal fauna, clearly derived from the littoral and not at all modified, may have originated quite recently.

These conclusions agree perfectly with those of Professor Forel, though in the Lake of Geneva the abyssal fauna has undergone some modification. The biology of the lakes indicates a very recent origin.

Phosphorescence.—No trace of luminosity has been observed among the fresh-water plankton-fauna, though it has been looked for under suitable conditions. The chemical composition of fresh water would no doubt lead one not to expect luminosity, yet it seemed worth while to look out for it, and put the negative result on record.[1]

CONCLUSION

The shortcomings of this Report are sufficiently obvious—the inequality of the work, and the total neglect of large sections of the field. Many points of interest in the biology are not touched upon, for lack of time to do so adequately. The including of previous work in the same field, especially the work of Dr Scott and Messrs W. and G. S. West, which would have greatly added to the value of the compilation, was prevented by lack of time to go over the literature with sufficient care.

Finally, the interruption of the work when still far from complete, and the consequent necessity for bringing it to a conclusion somehow, caused parts of it to be written with a haste which is highly undesirable when accurate results are aimed at. Nevertheless, with all these disadvantages, it seemed well that some summary of the biological work done by the Lake Survey should be attempted. If it fail in all other respects, it at least provides a trustworthy series of records of the life in the Scottish lochs, which should be of some service to other students.

[1] It is stated that Loch Builg in Aberdeenshire occasionally exhibits luminosity, but the observations recorded are not conclusive, and both the occurrence and its cause call for further investigation (see article by Thomas Jamieson in the *Aberdeen Free Press*, Nov. 19, 1908).

PART II

CENSUS OF THE SPECIES

Mollusca.—No study of the shells has yet been made by the Lake Survey. Information will be found in Dr Scott's papers. A few species only were noted.

1. *Limnæa peregra* (Müll.). Common.
2. *L. ovata* (Drap.). (*Teste* Dr Wesenberg-Lund.)
3. *Planorbis contortus* (Müll.). Abban Water (*teste* Dr Lund).
4. *Ancyclus fluviatilis*, L. Common.
5. *Pisidium pusillum* (Gmel.). (*Teste* J. W. Taylor.) In the bottom muds down to 750 feet.
6. *Anodonta cygnea* (L.). Common, especially in Lowland lochs.
7. *Unio margaritifer* (L.). Common in the large Highland lochs.

Hydrachnida.—The Water-Mites of the Scottish Lochs have not been adequately studied. A few species have been named by Mr C. D. Soar and Mr Wm. Williamson, but these represent so few lochs that nothing can be said as to distribution. Mr Williamson found that the common species in all the collections from Orkney was *Huitfeldtia rectipes* (Thor.), a species not previously recorded for Britain, and indeed unknown save in Norway. Dr Johnston found the larvæ of a Mite alive, in great numbers, in the stomach of a trout.

8. *Atax crassipes* (Müll.). Common.
9. *Piona obturbans*, Pierzig. Loch Rannoch ♀.
10. *P. paucipora*, Thor. Loch Rannoch ♂, Loch Laidon.
11. *P. fuscatus*, Herm. Dubh Lochan.
12. *P. carnea*, Koch. Perth and Sutherland.
13. *P. rufa*, Koch. Sutherland.
14. *P. aduncopalpis*, Herm. Loch Uanagan.
15. *Pionacercus*, sp. Loch Rannoch.
16. *Oxus ovalis*, Müll. Loch Rannoch.
17. *Hygrobates longipalpis*, Herm. Common.
18. *H. reticulatus*, Kram. Loch Ness, Loch Morar.
19. *Hydrochorentes ungulatus*, Koch. Dubh Lochan.
20. *H. krameri*, Pier. Loch Ness.
21. *Lebertea porosa*, Thor. Loch Ness.
22. *Hydrachna globosa*, De Geer. Common.
23. *Huitfeldtia rectipes* (Thor.). Common in Orkney.
24. *Arrhenurus*, sp. St Mary's Loch.

Tardigrada.—Of the 41 species of Tardigrada recorded for Scotland, 30 have been found in the lochs. Since the publication of the paper on Scottish Tardigrada,[1] two species, *Macrobiotus islandicus* and *M. macronyx*, have been deleted from the list, and *M. tetradactylus* has been added. Few of them are exclusively aquatic species. Most of them are at home among ground moss, and are casual in lakes. Four species are truly aquatic—*M. dispar*, *M. ambiguus*, *M. hastatus*, and *M. annulatus*. Three others are only known in this country from lake-margins—*Echiniscus reticulatus*, *M. papillifer*, and *M. pullari*.

25. *Echiniscus arctomys*, Ehr. Common.
26. *E. mutabilis*, Murray. Common.
27. *E. gladiator*, Murray. Loch Ness, Loch Morar.
28. *E. wendti*, Richters. Loch Morar, Loch Earn, Loch Tay.
29. *E. reticulatus*, Murray. Loch Morar, Loch Ness, Loch Earn.
30. *E. oihonnæ*, Richters. Loch Ness, Loch Earn.
31. *E. granulatus*, Doy. Loch Morar, Loch Ness, Loch Tay.
32. *E. spitsbergensis*, Scourfield. Loch Morar, Loch Earn.
33. *E. quadrispinosus*, Richters. Loch Morar, Loch Ness.
34. *Milnesium tardigradum*, Doy. Loch Ness.
35. *Macrobiotus hufelandii*, Sch. Common.
36. *M. intermedius*, Plate. Loch Morar.
37. *M. echinogenitus*, Richters. Common.
38. *M. dispar*, Murray. Loch Tay.
39. *M. ambiguus*, Murray. Loch Ness.
40. *M. pullari*, Murray. Gryfe Reservoir.
41. *M. hastatus*, Murray. Loch Tay.
42. *M. oberhäuseri*, Doy. Loch Ness.
43. *M. ornatus*, Richters. Loch Ness.
44. *M. tuberculatus*, Plate. Loch Morar.
45. *M. sattleri*, Richters. Loch Earn.
46. *M. papillifer*, Murray. Loch Ness, Loch Morar.
47. *M. annulatus*, Murray. Loch Morar.
48. *M. tetradactylus*, Greeff. Loch Ness.
49. *Diphascon chilenense*, Plate. Common.
50. *D. spitzbergensis*, Richters. Loch Ness.
51. *D. angustatum*, Murray. Loch Ness.
52. *D. scoticum*, Murray. Loch Morar.
53. *D. bullatum*, Murray. Loch Leven.
54. *D. oculatum*, Murray. Loch Ness.

Insecta.—There was no entomologist on the Lake Survey staff, nor were Insects even specially collected, except in a few lochs, and those among the deeper lochs, where insect life is not very abundant. Incidentally a few species have been noted. A few beetles, etc.,

[1] *Trans. Roy. Soc. Edin.*, vol. xlv. p. 642, 1907.

submitted to Mr Percy H. Grimshaw are reported upon at the end of this paper.

55. *Chironomus* (Blood-worm).—Larvæ very common; found in the plankton-nets and also in mud, as deep as 750 feet in Loch Ness.
56. *Corethra.*—Larvæ occasionally abundant in lochs, though commoner in ponds.
57. *Oxyethira*, sp.—Larvæ of this Caddis, in beautiful flask-like green cases, are often abundant in the margins and bottoms of lochs, sometimes going down to considerable depths, as in Loch Eilt and Loch Oich; Inchnacardoch Bay, Loch Ness.
58. *Dytiscus marginalis*, L. Loch Earn.
59. *Haliplus fulvus*, L. Harperleas Reservoir.
60. *H. ruficollis*, De G. Harperleas Reservoir.
61. *Corixa striata*, Fièb. Harperleas Reservoir.

Larvæ of many Diptera, Trichoptera, Perlidæ, Ephemeridæ, etc., have been collected.

Crustacea.—Being the most conspicuous animals in the plankton of the lochs, the Crustacea have received more attention than the more microscopic animals. The Crustacea of the littoral region have been studied by Mr Scourfield in two systems of lochs, and Mr Scourfield has further assisted by naming any species sent to him. The list contains 78 species, most of which are common and generally distributed. *Ilyocryptus acutifrons*, Sars, and *Ophryoxus gracilis*, Sars, were not previously known to live in Britain. Fuller information about the distribution of the species, with an account of many species not observed by the Lake Survey, will be found in Dr Scott's papers on the Inland Waters of Scotland (*Scot. Fish. Board Reports*, 1890 to 1899).

Isopoda.— 62. *Asellus aquaticus*, L.
Amphipoda.—63. *Gammarus pulex*, Fabr.
Schizopoda.—64. *Mysis vulgaris*, Thomps.
Copepoda.— 65. *Diaptomus gracilis*, Sars.
66. *D. laciniatus*, Lillje.
67. *D. laticeps*, Sars.
68. *D. wierzejskii*, Richard.
69. *Cyclops affinis*, Sars.
70. *C. albidus* (Jurine).
71. *C. bicuspidatus*, Claus.
72. *C. fimbriatus*, Fischer.
73. *C. fuscus* (Jurine).

74. *C. languidoides*, Lillje.
75. *C. languidus*, Sars.
76. *C. macrurus*, Sars.
77. *C. nanus*, Sars.
78. *C. prasinus* (Jurine).
79. *C. serrulatus*,[1] Fischer.
80. *C. strenuus*, Fischer.
81. *C. vernalis*, Fischer.
82. *C. viridis* (Jurine).
83. *Canthocamptus crassus*, Sars.
84. *C. hirticornis*, Scott.
85. *C. horridus*, Fischer.
86. *C. minutus* (Claus) = *C. lucidulus*, Rchberg.
87. *C. pygmæus*, Sars.
88. *C. zschokkei*, Schmeil.
89. *Moraria brevipes*, Sars.
90. *Achtheres percarum*, Nordmann.

Cladocera.—91. *Sida crystallina* (Müll.).
92. *Diaphanosoma brachyurum*, Liévin.
93. *D. leuchtenbergianum*, Fischer.
94. *Latona setifera* (Müll.).
95. *Holopedium gibberum*, Zaddach.
96. *Daphnia hyalina*, Leydig.
97. *Scaphloberis mucronata* (Müll.).
98. *Simocephalus vetulus* (Müll.).
99. *S. exspinosus* (Koch)?
100. *Ceriodaphnia quadrangula* (Müll.).
101. *Bosmina longirostris* (Müll.).
102. *B. obtusirostris*,[2] Sars.
103. *B. coregoni*, Baird.
104. *Ophryoxus gracilis*, Sars.
105. *Ilyocryptus sordidus* (Liévin).
106. *I. acutifrons*, Sars.
107. *I. agilis*, Kurz.
108. *Lathonura rectirostris* (Müll.)?
109. *Streblocerus serricaudatus* (Fischer).
110. *Drepanothrix dentata* (Eurén.).
111. *Acantholeberis curvirostris* (Müll.).
112. *Eurycercus lamellatus* (Müll.).
113. *Camptocercus rectirostris*, Schödler.
114. *Acroperus harpæ*, Baird.
115. *Alonopsis elongata*, Sars.

[1] Includes the three forms: *C. serrulatus*, s. str., *C. varius*, and *C. macruroides*.
[2] Includes *B. longispina*.

116. *Lynceus*[1] *intermedius*, Sars.
117. *L. affinis*, Leydig.
118. *L. rusticus*, Scott.
119. *Leptorhyncus falcatus*, Sars.
120. *Graptoleberis testudinaria* (Fischer).
121. *Alonella excisa* (Fischer).
122. *A. nana* (Baird).
123. *Peratacantha truncata* (Müll.).
124. *Pleuroxus*[2] *lævis*, Sars.
125. *P. uncinatus*, Baird ?
126. *Chydorus ovalis*, Kurz.
127. *C. sphæricus* (Müll.).
128. *C. barbatus* (Brady).
129. *Monospilus dispar*, Sars.
130. *Polyphemus pediculus* (Linné).
131. *Bythotrephes longimanus*, Leydig.
132. *Leptodora kindti* (Focke).

Ostracoda.—133. *Cypria ophthalmica* (Jurine).
134. *Cypris fuscata* (Jurine).
135. *C. obliqua*, Brady.
136. *Cyclocypris lævis* (Müll.).
137. *C. serena* (Koch).
138. *Candona candida* (Müll.).
139. *C. elongata*, Brady and Norman.

Bryozoa.—No fresh-water Bryozoa were collected by the Lake Survey, no doubt chiefly because there was no one on the staff acquainted with the group. Dr Wesenberg-Lund, of Denmark, a specialist in the group, did not find any during his visit to Scotland, but he examined very few lochs. That Bryozoa exist in the lochs is known from the work of Mr Hood, of Dundee. He has collected 8 species, and 7 of these, enumerated below, were found in lochs in Perthshire sounded by the Lake Survey. Mr G. West found statoblasts of a species in a small loch in Fife which was not surveyed.

140. *Paludicella ehrenbergii*, Van Ben.
141. *Fredericella sultana*, Blum.
142. *Plumatella fruticosa*, All.
143. *P. repens*, L.
144. *P. emarginata*, All.
145. *P. punctata*, Hancock.
146. *Cristatella mucedo*, Cuvier.

[1] *Lynceus guttatus* has been found in Loch Morar and elsewhere.
[2] *Pleuroxus trigonellus* was found in a pond between Mallaig and Loch Morar.

Worms.—Of the various classes which are united under the convenient name of Worms, no one, except the Rotifera, has been studied systematically in more than a few lochs. Mr C. H. Martin gave some time to the study of the worms of Loch Tay and Loch Lomond, and I am indebted to him for the majority of the names in the following list. Mr John Hewitt also named a few species from Loch Ness and some other lochs. Though Worms do not appear to be very numerous in the lochs, no doubt the number (25) recorded below is far short of what might be expected from more careful study. So little attention has been given to the Worms that it would serve no purpose to attempt to trace the distribution. Most of the species in the list are only recorded for one or two lochs, but there can be no doubt that most of them are in all the lochs.

Oligochæta.—
147. *Æolosoma ehrenbergi*, Oerst. Lochs Ness, Morar, etc.; common.
148. *Æ.*, sp. (green-spotted). Loch Ness.
149. *Stylodrilus Gabretea*, Vejd. (*teste* C. H. Martin). Abyssal; occasionally in shallow water.
150. *Stylaria lacustris*, L. Common.
151. *S. lomondi* (Martin). Loch Lomond.
152. *Lumbriculus*, sp. (*teste* J. Hewitt).
153. *Chætogaster*, sp. Common.

Hirudinea.—
154. *Hirudo medicinalis*, L. Loch Earn.
155. *Clepsine bioculata*, Sav. Loch Tay (*teste* C. H. Martin).
156. *C. sexoculata.* Loch Tay (*teste* C. H. Martin).

Nematoda.—
157. *Gordius*, sp. Loch Lochy. Found by Dr J. F. Gemmill (*teste* C. H. Martin).
158. *Eubostrichus*? sp. Loch Lomond.

Acanthocephala.—
159. *Echinorhynchus proteus*, Westumb. In trout, larva in *Gammarus* (*teste* Martin).

Cestoda.—
160. *Bothriocephalus plicatus.* In *Salmo fario* (*teste* C. H. Martin).
161. *Archigetes sieboldii* (Ratz.). In *Stylaria* (*teste* C. H. Martin).

Turbellaria.—
162. *Polycelis nigra*, Ehr. (*teste* J. Hewitt).
163. *Dendrocœlum lacteum*, Oerst. (*teste* Hewitt).
164. *Microstoma lineare*, Oerst. Loch Tay (C. H. Martin).
165. *Stenostoma leucops*, O. Schm. Loch Tay (C. H. Martin).

166. *Mesostomum viridiatum.* Loch Tay (C. H. Martin).
167. *M. prorhynchus*, Loch Tay (C. H. Martin).
168. *Vortex truncatus*, Ehr. Loch Tay (C. H. Martin).
169. *Polycystis goettei*, Bresslau.
170. *Automolos morgiensis* (Du Plessis). Lochs Ness, Tay, Earn.
171. *Gyrator notops.*

Notes on the Species

Hirudo medicinalis, L.—Found in Loch Earn, the medicinal leech may readily be supposed to have been introduced. Dalzell, however, records it from a smaller and remote loch in the same district.

Eubostrichus? sp.—Certes[1] wrongly included in the genus *Eubostrichus*, Greeff, a curious worm, the position of which is not yet definitely settled. In the head is a long trumpet-shaped body which is said by Certes to be a dart, which can be protracted. The body is annulate, and each ring bears six spines, which form six longitudinal rows on the body. The form found in Loch Lomond is undoubtedly related to that provisionally named *Eubostrichus guernei* by Certes, but differs in having numerous spines on each ring, which do not form distinct longitudinal rows.

Microstoma lineare, Oerst.—Mr Martin found this species in Loch Tay feeding on *Hydra*, and carried out a very interesting investigation into the subsequent history of the nematocysts of the *Hydra.*

Automolos morgiensis (Du Plessis).—At depths of 20 feet to 500 feet in Loch Tay, over 700 feet in Loch Ness. Mr Martin states that those dredged from 500 feet in Loch Tay had no eyes.

Stylodrilus Gabreteæ, Vejd.—Like *Automolos morgiensis*, this is an abyssal species. It is general at depths of over 100 feet, but is sporadic in shallower waters.

Rotifera.—A larger number of Rotifers is recorded for the Scottish lochs than of any other class of animals or plants. This may be partly due to the fact that they are very numerous,—by closer work the list might easily be extended to 300, perhaps 400 species,—but may be partly accounted for by the attention paid to them, and the facility with which they can be transmitted alive to specialists. Some other classes which are poorly represented in these lists—Infusoria, for example—may be really more numerous. The single family of Desmids contains more species than any one family of Rotifers, and the Diatoms are probably equally numerous. Eleven

[1] *Mission Scientifique du Cap Horn*, Paris, 1889, p. 48.

species of Rotifera previously undescribed were found in the Scottish lochs. These are *Microdina paradoxa*, *Philodina flaviceps*, *P. humerosa*, *P. hamata*, *P. laticornis*, *Callidina angusticollis*, *C. longiceps*, *C. annulata*, *C. crucicornis*, *C. armata*, and *Notommata pumila*.

Rhizota.— 172. *Floscularia campanulata*, Dobie.
173. *F. ornata*, Ehr.
174. *F. pelagica*, Rouss. Frequent.
175. *F. mutabilis*, Bolton. Rare.
176. *Stephanoceros eichhorni*, Ehr. Rare.
177. *Œcistes crystallinus*, Ehr.
178. *Œ. brachiatus*, Huds. Frequent.
179. *Œ. serpentinus*, Gosse.
180. *Pseudœcistes rotifer*, Stenroos. Rare.
181. *Conochilus volvox*, Ehr. Common.
182. *C. unicornis*, Rouss. Common.

Bdelloida.—183. *Microdina paradoxa*, Murray. Frequent.
184. *Philodina roseola*, Ehr.
185. *P. citrina*, Ehr.
186. *P. erythrophthalma*, Ehr.
187. *P. megalotrocha*, Ehr. Frequent.
188. *P. brevipes*, Murray. Frequent.
189. *P. flaviceps*, Bryce. Common.
190. *P. nemoralis*, Bryce.
191. *P. decurvicornis*. Murray.
192. *P. acuticornis*, Murray. Frequent.
193. *P. rugosa*, Bryce.
194. *P. plena* (Bryce).
195. *P. alpium* (Ehr.).
196. *P. brycei* (Weber).
197. *P. humerosa*, Murray. Rare.
198. *P. hamata*, Murray. Rare.
199. *P. laticeps*, Murray. Frequent.
200. *P. laticornis*, Murray. Rare.
201. *P. macrostyla*, Ehr. Common.
202. *P. aculeata*, Ehr.
203. *Callidina hexodonta* (Berg.). Rare.
204. *C. rœperi* (Milne). Rare.
205. *C. angusticollis*, Murray. Common.
206. *C. pusilla*, Bryce. Rare.
207. *C. longiceps*, Murray. Rare.
208. *C. leitgebii*, Zel.
209. *C. annulata*, Murray.
210. *C. aspera*, Bryce.

211. *C. crenata*, Murray.
212. *C. lata*, Bryce.
213. *C. pulchra*, Murray.
214. *C. plicata*, Bryce. Common.
215. *C. quadricornifera*, Milne. Common.
216. *C. habita*, Bryce. Common.
217. *C. ehrenbergii*, Janson.
218. *C. papillosa*, Thompson.
219. *C. multispinosa*, Thompson.
220. *C. aculeata*, Milne. Rare.
221. *C. muricata*, Murray. Rare.
222. *C. crucicornis*, Murray. Rare.
223. *C. symbiotica*, Zel.
224. *C. armata*, Murray. Local.
225. *C. tetraodon*, Ehr.
226. *C. russeola*, Zel.
227. *C. magna*, Plate.
228. *Rotifer vulgaris*, Schrank. Frequent.
229. *R. neptunius*, Milne. Rare.
230. *R. citrinus*, Ehr.
231. *R. tardus*, Ehr. Frequent.
232. *R. longirostris* (Janson). Common.
233. *R. trisecatus*, Weber. Rare.
234. *R. macroceros*, Gosse. Frequent.
235. *R. socialis* (Kellicott). Frequent.
236. *Adineta vaga* (Davis).
237. *A. gracilis*, Janson.
238. *A. barbata*, Janson.
239. *A. tuberculosa*, Janson.

Ploïma.—240. *Microcodon clavus*, Ehr.
241. *Microcodides chlæna*, Gosse.
242. *M. robustus* (Glascott).
243. *Asplanchna priodonta*, Gosse. General.
244. *Ascomorpha ecaudis*, Perty.
245. *Synchæta pectinata*, Ehr.
246. *S. tremula*, Ehr.
247. *S. oblonga*, Ehr.
248. *S. grandis*, Zach. Rare.
249. *Polyarthra platyptera*, Ehr. General.
250. *P. euryptera*, Wier. Local.
251. *Triarthra longiseta*, Ehr. Local.
252. *Notops hyptopus*, Ehr.
253. *Albertia bernardi*, Hlava. Lochs Ness and Rannoch.
254. *Taphrocampa annulosa*, Gosse. Loch Ness.

255. *T. selenura*, Gosse.
256. *Notommata aurita*, Ehr.
257. *N. brachyota*, Ehr.
258. *N. tripus*, Ehr.
259. *N. torulosa* (Duj.).
260. *N. pumila*, Rouss.
261. *N. forcipata*, Gosse.
262. *Copeus cerberus*, Gosse.
263. *C. spicatus*, Huds.
264. *C. caudatus*, Collins.
265. *Proales petromyzon*, Ehr.
266. *P. parasita*, Ehr.
267. *P. caudata*, Bilfinger.
268. *P. sordida*, Gosse.
269. *P. daphnicola* (Thompson). Rare.
270. *Pleurotrocha parasitica*, Jennings.
271. *Furcularia longiseta*, Ehr.
272. *F. reinhardti*, Ehr.
273. *F. forficula*, Ehr.
274. *F. quadrangularis*, Glascott.
275. *Eosphora najas*, Ehr.
276. *E. digitata*, Ehr.
277. *Diglena grandis*, Gosse.
278. *D. forcipata*, Ehr.
279. *D. circinator*, Gosse.
280. *D. ferox*, Western.
281. *D. uncinata*, Milne.
282. *D. dromius*, Glascott.
283. *Arthroglena lutkeni*, Berg.
284. *Rattulus lophoessa* (Gosse).
285. *R. longiseta*, Schrank.
286. *R. scipio* (Gosse).
287. *Diurella porcellus* (Gosse).
288. *D. brachyura* (Gosse).
289. *D. tenuior* (Gosse).
290. *D. tigris*, Müll.
291. *Dinocharis tetractis*, Ehr.
292. *D. similis*, Stenroos.
293. *D. pocillum*, Ehr.
294. *Polychætus collinsii*, Gosse.
295. *P. subquadratus*, Perty.
296. *Scaridium longicaudatum*, Ehr.
297. *Stephanops stylatus*, Milne.
298. *S. tenellus*, Bryce.

299. *Diaschiza gibba* (Ehr.).
300. *D. tenuior*, Gosse.
301. *D. sterea*, Gosse.
302. *D. lacinulata*, Müll.
303. *D. ventripes*, Dix-Nutt.
304. *D. hoodii*, Gosse.
305. *D. tenuiseta*, Burn.
306. *D. eva*, Gosse.
307. *Salpina mucronata*, Ehr.
308. *S. mutica*, Perty.
309. *Euchlanis lyra*, Huds.
310. *E. oropha*, Gosse.
311. *E. dilatata*, Ehr.
312. *E. deflexa*, Gosse.
313. *E. triquetra*, Ehr.
314. *Cathypna luna*, Ehr.
315. *C. rusticula*, Gosse.
316. *C. ligona*, Dunlop.
317. *C. latifrons*, Gosse.
318. *Distyla flexilis*, Gosse.
319. *D. depressa*, Bryce.
320. *Monostyla lunaris*, Ehr.
321. *M. cornuta*, Ehr.
322. *M. bulla*, Gosse.
323. *Metopidia lepadella* (Ehr.).
324. *M. solidus*, Gosse.
325. *M. rhomboides*, Gosse.
326. *M. acuminata*, Ehr.
327. *M. triptera*, Ehr.
328. *M. oxysternum*, Gosse.
329. *Colurus bicuspidatus*, Ehr.
330. *C. leptus*, Gosse.
331. *C. obtusus*, Gosse.
332. *C. tesselatus*, Glascott.
333. *Pterodina reflexa*, Gosse.
334. *P. patina*, Ehr.
335. *P. truncata*, Gosse.
336. *P. cæca*, Parsons.
337. *P. elliptica*, Ehr.
338. *Brachionus pala*, Ehr.
339. *B. angularis*, Gosse.
340. *Noteus quadricornis*, Ehr.
341. *Anuræa cochlearis*, Gosse.
342. *A. aculeata*, Ehr.

343. *A. hypelasma*, Gosse.
344. *Notholca longispina*, Kell.
345. *N. foliacea*, Ehr.
346. *N. striata*, Ehr.
347. *Eretmia cubeutes?* Gosse.
348. *Plœsoma truncatum*, Levander.
349. *P. hudsoni*, Imhof.
350. *P. triacanthum*, Berg.
351. *Gastropus stylifer*, Imhof.
352. *Anapus testudo*, Lauterborn.

Gastrotricha.—Several species of this neglected but highly interesting order have been observed. Lack of precise information and literature prevented the identification of any but two of the commonest species.

353. *Chætonotus larus*, Müll. Loch Ness.
354. *Ichthydium podura*, Müll. Loch Ness.

Cœlenterata.—The distinctions between the several species of *Hydra* are not very precise, and appear to be sometimes no more than differences of colour.

355. *Hydra vulgaris*, Pallas. Lochs Ness and Oich.

H. rubra and *H. fusca* are noted for Lochs Ness and Tay, but I am not certain whether these can be separated from the common *Hydra*. The distinct green species (*H. viridis*) has not been observed in the lochs, but Mr Scourfield found it in a pond between Mallaig and Loch Morar.

Porifera.—356. *Spongilla lacustris*, Carter. Spicules are frequently found in the tow-nets.

Finger-like stalks of a sponge have been found in Loch a' Mhuilinn, Beauly basin, and in Loch Meiklie (G. West). Mr J. Hewitt also reports gemmule of *Spongilla* from Loch a' Vullan (Ness basin).

Ciliata.—Only a few species of ciliate Infusoria were identified, chiefly in Loch Ness.

357. *Amphileptus gigas*, C. and L. Loch Ness.
358. *Trachelocerca olor*, Müll. Loch Ness.
359. *Trachelius ovum*, Ehr. Loch Ness.
360. *Toxophyllum meleagris*, Müll. Frequent.
361. *Chætospira muscicola*, Loch Ness.
362. *Stentor viridis*, Loch Ness.
363. *S. cæruleus*, Ehr. Frequent.
364. *S. niger*, Ehr. Lochs Oich and Uanagan. Frequent.
365. *S. polymorpha*, Müll. Loch Ness.

366. *S. pediculatus*, From. Loch Ness.
367. *Aspidisca turrita* (Ehr.). Loch Ness.
368. *Vorticella campanula*, Ehr. Loch Morar.
369. *Ophridium versatile*, Müll. Common in the smaller lochs, colonies reaching to a diameter of 6 inches.
370. Shells of *Tintinnidium* were frequent in the northern lochs, and a
371. *Tintinnus*, species not identified, was living in the Loch of Stenness in Orkney.

Sarcodina.—For work of any value on the Rhizopods and Heliozoa the Lake Survey is indebted to Dr Penard, of Geneva, the members of the staff having done nothing further than to extend the knowledge of distribution.

Amœbœa.—372. *Amœba granulosa*, Grub.
373. *A. radiosa*, Ehr.

Testacea.—374. *Cochliopodium bilimbosum* (Auerbach).
375. *Difflugia acuminata*, Ehr.
376. *D. arcula*, Leidy.
377. *D. bacillifera*, Pen.
378. *D. constricta*, Ehr.
379. *D. corona*, Wallich.
380. *D. curvicaulis*, Pen.
381. *D. globulosa*, Duj.
382. *D. gramen*, Pen.
383. *D. lanceolata*, Pen.
384. *D. lobostoma*, Leidy.
385. *D. pristis*, Pen.
386. *D. pyriformis*, Perty.
387. *D. urceolata*, Carter.
388. *Centropyxis aculeata*, Stein.
389. *Pontigulasia bigibbosa*, Pen.
390. *Lecquereusia modesta*, Rhumbler.
391. *L. spiralis* (Ehr.).
392. *Heleopera petricola*, Leidy.
393. *H. rosea*, Pen.
394. *Hyalosphenia papilio*, Leidy.
395. *H. cuneata*, Stein.
396. *H. elegans*, Leidy.
397. *Nebela americana*, Taranek.
398. *N. barbata*, Leidy.
399. *N. bicornis*, West.
400. *N. bursella*, Vejd.
401. *N. carinata*, Archer.

402. *N. caudata*, Leidy.
403. *N. collaris*, Leidy.
404. *N. crenulata*, Pen.
405. *N. flabellulum*, Leidy.
406. *N. lageniformis*, Pen.
407. *N. militaris*, Pen.
408. *N. tubulosa*, Pen.
409. *N. vitræa*, Pen.
410. *Quadrula symmetrica*, Schultze.
411. *Arcella hemispherica*, Perty.
412. *A. vulgaris*, Ehr.
413. *A. discoides*, Ehr.
414. *A. artocrea*, Leidy.

Filosa.— 415. *Cyphoderia ampulla* (Ehr.)
416. *Campascus minutus*, Pen.
417. *Assulina seminulum*, Leidy.
418. *A. minor*, Pen.
419. *Corythion dubium*, Taranek.
420. *Euglypha alveolata*, Duj.
421. *E. brachiata*, Leidy.
422. *E. ciliata* (Ehr.).
423. *E. compressa*, Carter.
424. *Placocysta spinosa*, Carter.
425. *P. lens*, Pen.
426. *Paulinella chromatophora*, Lauterborn.
427. *Pseudodifflugia horrida*, Pen.
428. *Sphenoderia lenta*, Schlumb.
429. *S. dentata*, Pen.
430. *Trinema enchelys* (Ehr.).
431. *T. lineare*, Pen.

Foraminifera.— 432. *Gromia nigricans*, Pen.

Aphrothoraca.— 433. *Actinophrys sol*, Ehr.
434. *Actinospherium eichhorni* (Ehr.).

Chalarothoraca.—435. *Acanthocystis chætophora*, Schrank.
436. *A. myriospina*, Pen.
437. *A. turfacea*, Pen.
438. *Pomphalyxophrys exigua* (Hert. and Less.).
439. *Raphidiophrys pallida*, Schultze.
440. *R. conglobata* (Greeff).

Desmothoraca.— 441. *Clathrulina elegans*, Cienk.

Suctoria.—On *Cyclops viridis*, dredged from the bottom of Loch Ness, there were often numbers of a tentaculiferous parasite.

442. *Podophrya cyclopum*, C. and L. (identified by Mr Scour-

field). Forel[1] gives *P. cyclopum* as found in the pelagic region, and *Acineta elegans*, Imhof, as occurring on Entomostraca in the abyssal region.

Flagellata.—443. *Dinobryon.*—How many species of *Dinobryon* are to be admitted I know not. In the Scottish lochs are found the forms or species *divergens*, Imh.; *cylindricum*, Imh.; *stipitatum*, Stenr.; and *elongatum*, Imh.

444. *Mallomonas plœssli*, Perty. Common.
445. *Synura uvella*. Ehr.
446. *Uroglena volvox*, Ehr. Loch Uanagan.
447. *Cryptomonas ovata*, Ehr.

Phanerogamia.—The following list of flowering plants is in great part extracted from a paper by G. West,[2] who examined some of the lochs of the Ness and other basins. Though I have added a few plants which were not found in the lochs visited by Mr West, this list is shorter than his. As Mr West remarks in his paper, while there is no doubt about the aquatic plants, there is room for difference of opinion as to what semi-aquatic plants should be admitted, and I have drawn the line closer and omitted many of his semi-aquatics. Some plants are so adaptable that they are capable of living a perfectly aquatic or completely terrestrial life.

448. *Ranunculus hederaceus*, L.
449. *R. flammula*, L.
450. *R. circinatus*, Sibth.
451. *Caltha palustris*, L.
452. *Castalia speciosa*, Salisb.
453. *Nymphæa lutea*, L.
454. *N. pumila*, Hoffm.
455. *N. alba*, L.
456. *Comarum palustre*, L.
457. *Peplis portula*, L.
458. *Lythrum salicaria*, L.
459. *Epilobium palustre*, L.
460. *Hippuris vulgaris*, L.
461. *Myriophyllum alterniflorum*, *D. C.*
462. *M. spicatum*, L.
463. *Callitriche stagnalis*, Scop.
464. *C. hamulata*, Kütz.
465. *Montia fontana*, L.
466. *Hydrocotyle vulgaris*, L.

[1] *Le Léman*, vol. iii. p. 131.
[2] *Proc. Roy. Soc. Edin.*, vol. xxv. p. 967, 1905.

467. *Apium inundatum*, Reichb.
468. *Œnanthe crocata*, L.
469. *Cicuta virosa*, L.
470. *Galium palustre*, L.
471. *Lobelia dortmanna*, L.
472. *Menyanthes trifoliata*, L.
473. *Myosotis palustris*, With.
474. *Veronica anagallis*, L.
475. *Scrophularia aquatica*, L.
476. *Mentha sativa*, L.
477. *Utricularia vulgaris*, L.
478. *U. intermedia*, Hayne.
479. *Littorella lacustris*, L.
480. *Polygonum amphibium*, L.
481. *P. hydropiper*, L.
482. *Iris pseudacorus*, L.
483. *Alisma plantago*, L.
484. *Stratiotes aloïdes*, L.
485. *Elodea canadensis*, Mich.
486. *Juncus effusus*, L.
487. *J. bufonius*, L.
488. *J. articulatus*, L.
489. *Typha latifolia*, L.
490. *T. angustifolia*, L.
491. *Sparganium ramosum*, Huds.
492. *S. natans*, L.
493. *Potamogeton natans*, L.
494. *P. polygonifolius*, Pourr.
495. *P. lucens*, L.
496. *P. prælongus*, Wulf.
497. *P. crispus*, L.
498. *P. perfoliatus*, L.
499. *P. pusillus*, L.
500. *P. filiformis*, Pers.
501. *Ruppia maritima*, L.
502. *Zannichellia palustris*, L.
503. *Heliocharis palustris*, Br.
504. *Scirpus lacustris*, L.
505. *Carex elata*, All.
506. *C. aquatilis*, Wahl.
507. *C. rostrata*, Stokes.
508. *C. vesicaria*, L.
509. *Phalaris arundinacea*, L.
510. *Phragmites communis*, Trin.

511. *Glyceria fluitans*, Br.
512. *G. aquatica*, Sm.

Equisetaceæ.— 513. *Equisetum limosum*, L.

Selaginellaceæ.—514. *Isoetes lacustris*, L.

Characeæ.— 515. *Nitella opaca*, Ag.
516. *N. translucens*, Ag.
517. *Chara aspera*, Willd.
518. *C. fragilis*, Desv.
519. *C. fœtida*, Al. Br.
520. *C. hispida*, L.

Muscinæ.— 521. *Sphagnum cuspidatum*, Ehr.
522. *Rhacomitrium aciculare*, Brid.
523. *Grimmia apocarpa*, Hedw.
524. *Cinclidotus fontinaloides* (Lamarck). Loch Morar.
525. *Philonotis fontana*, Brid.
526. *Fontinalis antipyretica*, L. Very common.
527. *Porotrichum alopecurum* (L.). Loch Morar.
528. *Climacium dendroides*, W. and M. Loch Ness, Loch Lomond.
529. *Brachythecium rivulare*, B. and S.
530. *Eurhynchium rusciforme*, Milde.
531. *Hypnum fluitans*, L.
532. *H. falcatum*, Brid.
533. *H. ochraceum*, Turn. Loch Ness.
534. *H. scorpioides*, L.
535. *H. stramineum*, Dicks.
536. *H. cuspidatum*, L.
537. *Pterogonium gracile*, Swartz.
538. *Ulota hutchinsiæ* (Sm.).

Hepaticæ.— 539. *Scapania undulata*, L.
540. *Nardia emarginata*, Ehr.

Algæ

Florideæ.— 541. *Batrachospermum moniliforme*, Roth.
542. *Sacheria* (*Lemana*), sp.

Chlorophyceæ.— 543. *Bulbochæte*, sp.
544. *Œdogonium capillare*, L.
545. *Enteromorpha intestinalis* (L.)
546. *Draparnaldia glomerata* (Vauch.).
547. *Conferva fontinalis*, Berk.
548. *Cladophora fracta*, Dillw.
549. *Mougeotia*, sp.

550. *Zygnema vaucherii*, Ag.
551. *Spirogyra crassa*, Kütz.

Desmidiaceæ.—552. *Gonatozygon monotænium*, De Bary.
553. *Spirotænia condensata*, Bréb. Common.
554. *Penium spirostriolatum*, Barker. Loch Rannoch.
555. *Netrium digitus* (Ehr.). Common.
556. *N. interruptum*, Bréb. Loch Ness.
557. *N. nagelii* (Bréb.). Loch Ness.
558. *Closterium calosporum*, Wittr. Loch na Meide.
559. *C. cornu*, Ehr. Frequent.
560. *C. costatum*, Corda. Loch Rannoch.
561. *C. didymotocum*, Corda. Frequent.
562. *C. ehrenbergii*, Menegh. Caithness.
563. *C. kutzingii*, Näg. Common.
564. *C. lineatum*, Ehr. Loch Rannoch.
565. *C. lunula* (Müll.). Common.
566. *C. ralfsii*, Bréb. Loch Ness.
567. *C. rostratum*, Ehr. Loch Ness.
568. *C. setaceum*, Ehr. Common.
569. *C. striolatum*, Ehr. Loch Rannoch.
570. *Pleurotænium coronatum*, Bréb. Common in the north.
571. *P. nodosum* (Bréb.). Sutherland.
572. *Docidium undulatum*, Bail.
573. *Tetmemorus granulatus* (Bréb.). Common.
574. *Euastrum affine*, Ralfs. Common.
575. *E. ansatum*, Ralfs. Common.
576. *E. bidentatum*, Näg. Common.
577. *E. binale* (Turp.). Common.
578. *E. crassum* (Bréb.). Common.
579. *E. denticulatum* (Kirchn.). Common.
580. *E. didelta* (Turp.). Common.
581. *E. divaricatum*, Lund. Loch Rannoch.
582. *E. inerme* (Ralfs). Sutherland.
583. *E. oblongum* (Grev.). Common.
584. *E. pectinatum* (Bréb.). Common.
585. *E. sinuosum*, Lenorm. Loch Ness.
586. *E. verrucosum*, Ehr. Very common.
587. *Micrasterias americana* (Ehr.). Loch Ness.
588. *M. apiculata*, Ehr. Common in the north.
589. *M. brachyptera*, Lund. Loch Ness.
590. *M. conferta*, Lund. Common in the north.
591. *M. denticulata*, Bréb. Common.
592. *M. jenneri*, Ralfs. Loch Ness.

593. *M. mahabuleshwarensis*, Hobson. Very local.
594. *M. murrayi*, West. Sutherland; Ayrshire.
595. *M. papillifera*, Bréb. Common.
596. *M. pinnatafida* (Kütz.). Loch na Doire Daraich, Sutherland.
597. *M. radiata*, Hass. Local.
598. *M. rotata* (Grev.). Common.
599. *M. sol* (Ehr.). Common.
600. *M. thomasiana*, Arch. Common.
601. *M. truncata* (Corda). Common.
602. *M. verrucosa*, Bissett. Loch Ness.
603. *Xanthidium aculeatum*, Ehr. Loch Rannoch.
604. *X. antilopeum* (Bréb.). Common.
605. *X. armatum* (Bréb.). Common.
606. *X. controversum*, West. Local.
607. *X. cristatum*, Bréb. Common.
608. *X. subhastiferum*, West. Local.
609. *Cosmarium botrytis* (Bory). Common.
610. *C. brebissoni*, Menegh. Ross.
611. *C. capitulum*, Roy and Biss. Sutherland, Ross.
612. *C. connatum*, Bréb. Sutherland.
613. *C. crenatum*, Ralfs. Sutherland.
614. *C. cucumis* (Corda). Perth; Sutherland.
615. *C. galeritum*, Nordst. Loch Ness.
616. *C. humile* (Gay). Sutherland.
617. *C. ovale*, Ralfs. Frequent.
618. *C. pachydermum*, Lund. Perth; Sutherland.
619. *C. phaseolus*, Bréb. Caithness.
620. *C. plicatum*, Reinsch.
621. *C. punctulatum*, Bréb. Perth; Inverness.
622. *C. ralfsii*, Bréb. Perth.
623. *C. reniforme* (Ralfs). Local.
624. *C. subspeciosum*, Nordst. Frequent.
625. *C. tetraophthalmum* (Kütz.). Sutherland.
626. *Cosmocladium constrictum*, Arch. Frequent.
627. *Staurastrum anatinum*, Cooke and Wills.
628. *S. angulatum*, West. Sutherland.
629. *S. arctiscon*, Ehr. Frequent, but local.
630. *S. aristiferum*, Ralfs. Loch Naver, Sutherland.
631. *S. aversum*, Lund. Common.
632. *S. avicula*, Bréb. Common.
633. *S. bifidum*, Bréb. Loch Bad a' Ghaill.
634. *S. brachiatum*, Ralfs. Loch nan Cuinne.
635. *S. brasiliense*, Nordst. Frequent, but local.

636. *S. brevispinum*, Bréb. Local.
637. *S. curvatum*, West. Common.
638. *S. cuspidatum*, Bréb. Common.
639. *S. dejectum*, Bréb. Frequent.
640. *S. erasum*, Bréb. Local.
641. *S. furcigerum*, Bréb. Common.
642. *S. gracile*, Ralfs. Common.
643. *S. grande*, Buln. Local.
644. *S. hibernicum*, West. Sutherland.
645. *S. inelegans*, West. Loch Skinaskink, Sutherland.
646. *S. jaculiferum*, West. Common.
647. *S. longispinum* (Bail.). Local.
648. *S. lunatum*, Ralfs. Common.
649. *S. megacanthum*, Lund. Local.
650. *S. ophiura*, Lund. Local.
651. *S. paradoxum*, Meyen. Common.
652. *S. pilosum* (Näg.).
653. *S. polymorphum*, Bréb. Common.
654. *S. pseudopelagicum*, West. Common.
655. *S. sexangulare* (Buln.). Local.
656. *S. subpygmæum*, West. Sutherland.
657. *S. turgescens*, De Not. Perth and Sutherland.
658. *S. teliferum*, Ralfs. Caithness; Sutherland.
659. *S. tumidum*, Bréb. Sutherland.
660. *S. vestitum*, Ralfs.
661. *Arthrodesmus incus* (Bréb.). Common.
662. *A. convergens*, Ehr. Frequent.
663. *A. triangularis*, Lagerh. Sutherland.
664. *Sphærosoma*, sp.
665. *Desmidium swartzii*, Ag. Local.
666. *Hyalotheca mucosa* (Dillw.). Common.
667. *Gymnozyga moniliformis*, Ehr. Perth, Inverness.

Volvocineæ.— 668. *Volvox globator*, L.
669. *Eudorina elegans*, Ehr.
670. *Pandorina morum* (Müll.).
671. *Chlamydomonas adherens*, Bach.

Palmellaceæ.—672. *Pediastrum boryanum*, Turp.
673. *P. duplex*, Meyen.
674. *Dactylococcus*, sp.
675. *Scenedesmus antennatus*, Bréb.
676. *S. obliquus* (Turp.).
677. *Raphidium*, sp.
678. *Selenastrum bibraianum*, Reinsch.

679. *Tetraëdron limneticum*, Borge.
680. *Botryococcus braunii*, Kütz.
681. *Dictyospherium ehrenbergianum*, Näg.
682. *Nephrocytium agardhianum*, Näg.
683. *Urococcus insignis* (Hass.).
684. *Eremosphæra viridis*, De Bary.

Diatomaceæ.— 685. *Fragilaria crotonensis* (A. M. Edw.). Local.
686. *Rhizosolenia*, sp. Local.
687. *Cyclotella radiosa.*
688. *C. compta*, Kütz. Sutherland.
689. *Stauroneis anceps*, Ehr.
690. *Navicula gibba*, Kütz.
691. *N. alpina*, Kütz.
692. *N. nobilis*, Kütz.
693. *N. major*, Kütz.
694. *Vanheurckia rhomboides*, Bréb.
695. *Gomphonema acuminatum*, Ehr.
696. *G. dichotomum*, Kütz.
697. *Achnanthes exilis*, Kütz.
698. *Eunotia lunaris*, Ehr.
699. *E. gracilis*, Ehr.
700. *E. bidens*, Ehr.
701. *Synedra pulchella*, Kütz.
702. *S. ulna*, Ehr.
703. *Surirella robusta*, Ehr. Common.
704. *Asterionella formosa*, Hass. Common.
705. *A. gracillima*, Heib. Common.
706. *Tabellaria fenestrata*, Kütz. Common.
707. *T. flocculosa*, Kütz. Common.
708. *Campylodiscus*, sp.
709. *Melosira*, sp.
710. *Tetracyclus lacustris*, Ralfs.

Myxophyceæ.—711. *Rivularia*, sp.
712. *Glæotricha*, sp.
713. *Nostoc*, sp.
714. *Anabæna flos-aquæ* (Lyngb.). Common.
715. *A. circinalis*, Kütz. Common.
716. *Oscillatoria*, sp.
717. *Clathrocystis æruginosa* (Kütz.). Common.
718. *Glæocapsa*, sp.
719. *Cœlospherium kutzingianum*, Näg. Common.
720. *Gomphosphæria lacustris*, Chodat.

Dinoflagellata.—Only a few of the commonest species have been identified. Further information will be found in Messrs West's

"Fresh-water Plankton of Scottish Lochs."[1] Messrs West distinguish 12 species.

721. *Peridinium tabulatum*, Ehr. Common.
722. *Ceratium hirundinella*, Müll. Very common.
723. *C. cornutum* (Ehr.). Frequent.
724. *Glenodinium cinctum*, Ehr. Loch Ness.

INSECTS.

Mr Grimshaw has examined a small collection of insects, and given us some notes upon them. Most of them were in immature stages, and the species could not be identified, but Mr Grimshaw has indicated the families, and, where possible, the genera. The insects in the following list were all collected in Loch Ness.

Gerris ? costæ, H. Schff. (nymph).
Corixa præusta, Fieb.
C. fabricii, Fieb.
C. ? distincta, Fieb.

Ephemeridæ, nymphs of two species ; nymph of a large species probably belonging to the genus *Baëtis*.

Trichoptera, larvæ. Cases and larvæ of *Oxyethira* or other Hydroptilid.

Perlidæ, larvæ.
Culex sp., pupa.
Chironomidæ, larvæ.
Platambus maculatus, L.
Haliplus fulvus, L.
Hydroporus septentrionalis, Gyll.
Laccobius minutus, L.

[1] *Trans. Roy. Soc. Edin.*, vol. xli. p. 493, 1905.

SOME DISTINCTIVE CHARACTERS IN THE FRESH-WATER PLANKTON FROM VARIOUS ISLANDS OFF THE NORTH AND WEST COASTS OF SCOTLAND

By JOHN HEWITT, B.A.

It is now fairly well established that there is a great uniformity in the fresh-water plankton from all parts of the world; the means of dispersal of the numerous organisms constituting this assembly have been so efficient, and their adaptability to various environmental conditions, such as temperature, light, and chemical composition of the water, so great, that plankton from the Arctic and from the tropical regions have a great number of species in common. Nevertheless, there is a decided though somewhat inconspicuous differentiation according to climate, and, for example, it has been shown [1] that there is a certain association of zooplankton which belongs particularly to the Arctic and subalpine lakes; and moreover it has been known for a long time that in one family, the Diaptomidæ, the delimitation of the species is quite sharp, the English species of *Diaptomus* being unknown in the lakes of the New World; and when in addition to such considerations we take into account the relative abundance and variation of cosmopolitan forms which have predilection for certain environmental conditions, it becomes possible to roughly divide the world into several zoological regions which coincide with areas of different climatic conditions.

It has been pointed out by Mr James Murray [2] that Scotland occupies a more or less intermediate position between two such regions, and that northwards the plankton contains the Arctic and subalpine association, whilst in the lowlands the plankton is more closely related to that from the great European plain.

[1] Sven Ekman, "Die Phyllopoden, Cladoceren, etc., der nordschwedischen Hochgebirgen," *Zool. Jahrb. Abt. Syst. Geogr. Biol.*, Bd. xxi., 1904.

[2] James Murray, " Distribution of the Pelagic Organisms in Scottish Lakes," *Proc. Roy. Phys. Soc. Edin.*, vol. xvi. p. 51, 1905.

The islands (Shetlands, Orkneys, Lewis, North Uist, Benbecula, Mull, and Lismore) with which I am dealing in this present paper all have the northern type of plankton, but they do not agree together so completely as might have been expected; and the differences are sufficiently marked to enable one to readily distinguish between a tow-netting from the Shetlands, the Orkneys, or Lewis. In reality the Lewis plankton is very like, though not quite identical with, that of Ross-shire, whilst the Shetlands and Orkneys have each a more distinctive plankton. Nevertheless, if a complete list of all the species found in the Shetland lochs be compared with lists from the Orkneys or from Lewis, the differences will appear rather small, being for the most part varietal rather than specific. In this paper I am dealing with only three species of the plankton assembly, viz. *Daphnia longispina*, *Bosmina obtusirostris*, and *Ceratium hirundinella*, and it will be seen that the *Daphnia*, and to a less extent the *Bosmina*, are present as fairly definite varieties in the several regions considered. I think it very probable that investigation would bring out very similar facts for a number of other species of the plankton, *e.g.* *Bythotrephes longimanus*, *Leptodora hyalina*, various Rotifers and Desmids.

It should be mentioned that the material available for the following comparisons was simply the tow-nettings taken on the various lochs at the time when the Lake Survey happened to be stationed there; consequently each loch is represented by only one gathering; but as the various islands were visited by different members of the Survey staff at about the same time of the year, and that the best season for plankton-collecting, a comparison is justifiable. An examination of plankton from a number of lochs on each of these islands has provided the following distinctive characters:—

For the Shetlands, examined 30th June to 11th August 1903, a very definite variety of *Daphnia*, a small form of *Bosmina obtusirostris*, a marked abundance of *Diaptomus wierzejskii*, and apparently total absence of *Diaptomus laciniatus*, a general rarity of *Holopedium gibberum*, *Bythotrephes longimanus*, *Leptodora hyalina*, *Polyphemus pediculus*, and *Diaphanosoma brachyura*, and a great abundance of *Ceratium hirundinella.*

For the Orkneys, examined 15th to 27th August 1903, another variety of *Daphnia*; otherwise much like the Shetlands.

For Lewis, examined 10th July to 21st August 1903, *Daphnia* of a smaller type, a larger form of *Bosmina*, a marked abundance of *Diaptomus laciniatus* and apparently absence of *Diaptomus gracilis*, an abundance of *Holopedium gibberum*, *Leptodora hyalina*, *Diaphanosoma brachyura*, *Bythotrephes longimanus*, and *Polyphemus pediculus*, rarity of *Ceratium hirundinella*, and finally a specially rich development of Chlorophyceæ.

For North Uist and Benbecula, an abundance of *Diaptomus wierzejskii* and apparently absence of *Diaptomus laciniatus*; otherwise much like Lewis. The plankton material from Mull and the small island of Lismore is too small to justify an exact comparison with the above-mentioned areas, but I shall refer to it later on.

In the four areas which we have just distinguished the lochs differ somewhat in physical features:—(1) The Shetland lochs are mostly shallow, some few are relatively deep, and they are elevated 20 to 300 feet above sea-level; (2) the Orkney lochs are all broad, shallow, and flat-bottomed, and they are elevated about 50 feet; (3) of the lochs surveyed in Lewis, the greater part are relatively deep, some few are shallow, and they are elevated 100 to 400 feet above sea-level; (4) the North Uist and Benbecula lochs are nearly all shallow, a few are of moderate depth, and they are elevated only a few feet above sea-level. As regards the temperature of the waters in these same areas, there appears to be a small but decided difference, the Shetland lochs being colder than those of the other areas. In the following table I have given the surface temperatures taken in all the lochs of the islands which were visited by the Survey. As will be seen, the Lewis and Shetland lochs were surveyed contemporaneously, and at that time the Shetland lochs were superficially several degrees colder than those of Lewis; and I am supposing also that in general a like difference in thermal conditions would obtain for all the upper strata where the plankton organisms live. In North Uist and Benbecula the survey commenced in the second week of May, when the surface temperature was about 49° Fahr. After that a rapid warming of the waters took place, and by the fourth week in May the lochs had a surface temperature of over 60° Fahr., and early in June a maximum reading of 68° Fahr. was recorded. It should be noted, however, that the difference in the whole thermal conditions of these lochs is often not so great as would seem to be the case from a consideration of surface temperature alone, for in the heated lochs of early June there was actually found to be a very rapid fall of temperature in passing from the surface to the lower layers of water, in several cases a range of 16° Fahr. occurring in a vertical distance of only 20 or 25 feet. On the other hand, the colder lochs of early May had a more or less uniform temperature from top to bottom; further, it will be seen that the deeper lochs remained cooler than the shallower lochs of the same neighbourhood. So in all the areas under consideration, especially in North Uist, the tow-nettings were taken from lochs differing quite appreciably in their thermal conditions, and later on we shall see to what extent the plankton varies accordingly.

I must mention that the tow-nettings from the Shetlands, the Orkneys, and from Lewis were taken in the same year, 1903, but North Uist and Benbecula were surveyed in 1904.

TABLE SHOWING SURFACE TEMPERATURES (FAHR. SCALE) OF MOST OF THE LOCHS SURVEYED IN SHETLAND, ORKNEY, LEWIS, NORTH UIST, AND BENBECULA.

	Shetland.	Orkney.	Lewis.	N. Uist and Benbecula.
2nd week in May .	...	...	...	49·2, 51·0, 47·7, 49·0, 49·2, 49·3
3rd ,, ,, .	...	...	...	52·5, 52·0
4th ,, ,, .	...	...	...	61·0, 64·0, 63·0
1st week in June .	...	...	...	59·2, 61·0, 60·4, 64·6, 59·0, 68·0, 67·0, 66·7
2nd ,, ,, .	...	...	...	61·0, 58·8, 60·2
4th ,, ,, .	56·3, 55·6	...	...	60·0, 59·2, 55·0,* 59·2, 59·7, 55·2,* 55·5*
1st week in July .	55·3, 52·0, 58·5, 56·8	...	...	59·2, 58·0
2nd ,, ,, .	54·1,* 53·0, 54·8,* 55·8, 55·0, 54·4	...	56·9, 55·8	...
3rd ,, ,, .	56·8, 57·5, 54·8, 58·0, 54·2	...	56·1*	...
4th ,, ,, .	55·5, 56·0, 54·9	...	61·5,* 61·8, 59·0,* 56·5,* 57·0†	...
1st week in August .	54·8, 55·2, 56·4, 56·4, 53·8, 55·8, 56·0	...	58·0, 60·1, 58·0, 59·0, 60·0, 58·2*	...
2nd ,, ,, .	57·9, 58·0	57·0	59·0, 57·3, 58·0, 58·0*	...
3rd ,, ,, .	...	60·2, 58·0, 55·0, 58·5	59·2, 55·8,* 53·1, 55·4	...
4th ,, ,, .	...	57·7, 57·3, 58·6	...	...
1st week in September	...	64·6, 62·0	...	...
3rd ,, ,,	...	54·6, 53·5	...	...

* indicates a loch whose mean depth is over 20 feet.
† indicates a loch whose mean depth is over 100 feet.

Daphnia longispina, O. F. Müller.—The Daphnias of all the lakes under consideration are varieties of this protean species, and it occurs under different forms in the several areas. There is not sufficient material to justify a definite answer respecting the amount of seasonal variation that obtains for this species in our lakes, but the evidence, so far as it goes, would imply that seasonal variation, if it occurs at all, is not very pronounced, and I am inclined to regard the varieties dealt with below as fairly permanent local forms.

In the island of Lewis, a tow-netting from any one loch contains Daphnias of varied shape and size; usually the majority are slender forms with long posterior spines and galeate heads, whilst a few are larger and stouter creatures with rounded and protruding foreheads and shorter posterior spines. If young are present, they are relatively stout forms with slightly galeate heads and long posterior spines. When just about to leave the brood-pouch of the parent, the young Daphnia has a perfectly rounded head with no indication of galeation. Only on one occasion have I met with an exception to this rule: in Loch Valtos (15th August 1903) a late embryo, still in the parent's brood-pouch, had just the first beginnings of a galea on the head. In the same tow-netting there were advanced embryos which had perfectly rounded heads, so far as the outer shell was concerned; but within that shell the very delicate skin was slightly peaked, and at the succeeding moult the creature would have a correspondingly galeate head. But, as a general rule, however galeate the parent may be, its newly hatched young have rounded heads. Nevertheless it very quickly becomes galeate, and at every moult up to a certain stage the Daphnia becomes more pronouncedly so. Eventually the galeated Daphnias begin to produce parthenogenetic eggs, the number of individuals in a brood being very few, sometimes only one; but these adults, if such they may be called, still continue to grow, becoming at each moult stouter and at the same time less galeate. I have several times seen examples of such adults just at the moulting stage, and in such cases the new skin was seen to be closely approximated to the old one over the whole surface of the body, excepting the tip of the posterior spine and the anterior part of the head, where the new galea was considerably less acute than the old one (see Plate XIII. fig. 1, Loch Frisa). This reduction of the galea may continue until it disappears entirely and the creature has an absolutely rounded head. Not infrequently, however, the oldest Daphnias of a tow-netting show a reminiscence of the juvenile peak in the shape of a slight angularity on that part of the head (see Plate X. fig. 3, Loch Valtos).

In the specimen just referred to from Loch Frisa the tip of the newly formed posterior spine did not reach up to the end of the old one, the new spine being shorter than the old one by about one-sixth the length of the latter; this shortening of the spine, which at first is nearly as long as the body, and eventually may not be longer than one-sixth of the body-length—and, as we shall see, is reduced to a mere stump in the Orkneys—commences, I believe, at the early moults of the young and continues throughout life, being more pronounced, however, in the later stages of the animal's life.

In the island of Lewis there are lakes of widely different depth and shape, and there are corresponding differences in the temperature of these lakes; nevertheless the Daphnia varied but slightly from lake to lake. In Loch Suainaval (24th July), which is of great depth and has a small limnetic area, the adults have just an indication of a galea, while the young ones are decidedly galeate, but not much so. In Loch Langavat (16th July), a large loch of some depth, Daphnia was rare, and the only specimens found were adults with protruding foreheads, but no galea. In Loch a' Chlachain (10th July), a shallow loch, the young are pronouncedly galeate, and the adults but slightly so. In Loch Dhomhnuill Bhig (14th August), a shallow loch, the adults are round-heads and the young ones galeated. In Loch Trealaval (7th August) the old ones had round heads, the young ones were galeate, but not much so, and the youngest specimens were only very slightly galeate. In Loch Crò Criosdaig (4th August) all the Daphnias were slightly galeate. In these several forms the eye varies in size; generally it is relatively small in the galeated Daphnias, and moderate-sized or large in the round-head forms.

From this short sketch of the life-history of *Daphnia longispina* in the lakes of Lewis, it will be seen that *Daphnia galeata*, s. str., is here to be regarded as a juvenile form, whereas elsewhere—on the continent of Europe, for instance—such is not the case, for there this galeated form, though not a permanent species, attains its maximum size, and produces ephippia without losing the galea. The conclusion I have arrived at is based simply on the facts just detailed, viz. that from 10th July up to 21st August, during which time tow-nettings were taken from more than twenty lochs, the Daphnias of any of these lochs were of all sizes and of all stages of galeation, and that generally the most galeate forms were quite without summer eggs, whilst the largest forms, which also were the egg-bearing forms, had only slight galeation or had completely rounded heads. Sven Ekman states that in the mountain lakes of North Sweden the spring Daphnias belong to the forma *microcephala*, Sars; later on appears the forma *obtusifrons*, Sars, and the summer generations are of the forma *galeata*, Sars. It would appear, however, that in Lewis the differentiation into these several forms has only just commenced, and that, whilst there is a strong tendency towards galeation in the summer generations, this for the most part affects only the young, whilst the adults remain much the same throughout. According to Mr T. Scott, the galeated forms in Loch Oich and other lochs of the Highland region, whilst exhibiting some amount of variation, nevertheless on the whole preserve a large crest up to and throughout the egg-bearing period, and the males are all provided with a prominent crest; on the other hand, in the lakes of the islands under consideration I have never seen crested males, though in the very few cases where males were seen the females were galeated. It appears, therefore, that in some of the mainland lochs *Daphnia galeata* is a permanent form, so far as the summer season is concerned.

In the lakes of Lewis I have occasionally noticed that the Daphnias are only represented by two stages (*e.g.* the very galeate form without eggs, and the slightly galeate form with eggs), without many intermediates, as if the brood-formation were simultaneous throughout the adult Daphnia population, a phenomenon well known in the lakes of the Continent; but this is unusual in Lewis, and apparently a Daphnia produces in succession several series of summer eggs, with the result that Daphnias of all stages of the life-history are to be found at any time. In several of these lochs the older Daphnias had a purple coloration on some part of the valves, due to the deposit of pigment in granular form between the two chitinous layers of the valve; often, too, the internal body-tissues were tinged with a suffused purple colour. But coloration was most marked in the Diaptomus of Lewis, which was almost invariably a vivid blue, but occasionally was red.

Ephippium-bearing females were only rarely seen; in fact, I have taken them only in Loch Fadagoa (9th August), and the heads were rounded. I was unable to discover the males.

The adult round-head Daphnia of Lewis is about 1·8 mm. in length (including spine), the eyes are moderate-sized or large, and it agrees fairly well with the variety *obtusifrons*, Sars, or in a few cases the variety *microcephala*, Sars.

The Daphnias of North Uist and Benbecula were on the whole very similar to those of Lewis. The younger adults had a rather large and slightly galeate head, whilst the body was small and carried only one summer egg; the older ones had a smaller but rounded head, and the body was larger and carried three, four, sometimes six, or even eight summer eggs—the one figured from Loch Vieragvat had eight but this is rather exceptional.

There were considerable differences in the surface temperatures of the lochs, as North Uist was visited in the early summer, just when the thermal changes were most rapid. In Loch Skealtar, examined 9th May 1904, the surface temperature was 47°·7 Fahr.; its adult Daphnias had rounded heads, many of them having a faint indication of a peak, whilst the young were slightly but not markedly galeate.

In Loch Vieragvat, examined 12th May 1904, with a temperature of 49°·3 Fahr., the old Daphnias were large and stout, with the head quite rounded, some of them, however, showing indication that they had been galeate; the young were all quite definitely galeate, but not much so. In Loch na Coinnich, examined 7th June 1904, with a surface temperature of 68°·0 Fahr., some of the adults were large, the spine short and slender, the heads rounded, and they carried about seven or eight embryos; other adults—and these were numerous—had just a small galea (see Plate XI. fig. 2) and fewer summer eggs; the young were rather more galeate than in the lochs just mentioned. In Loch an Iasgaich, examined 9th June 1904, surface temperature 66°·0 Fahr., much the same conditions prevailed, except that Daphnias with completely rounded heads were wanting, though the oldest specimens had almost lost their galea. In Loch Langavat (Benbecula), examined 4th July 1904, with a surface temperature of 58°·0 Fahr., the adult Daphnias were mostly non-galeate, and the young ones very pronouncedly galeate. It seems very probable, then, that galeation in the Daphnias does increase, though not to a great extent, with the warming of the waters in summer.

In one or two lochs the adult Daphnias had a deposit of purple pigment on the post-ventral region of the valves, as was also the case in a few Lewis lochs; and I have seen very similar pigmentation in autumnal Daphnias from the lakes of Sutherland and Ross-shire. In Loch Maol a' Choire (Inver basin), a small lake at a considerable elevation, the pigment was deposited in two dorsal areas—one just behind the head, and the other posteriorly; more usually, however, such Daphnias have only one pigment spot, situated, as in North Uist, post-ventrally. Sven Ekman records the same kind of coloration in the *D. galeata* of Puorek Lake.

No males or ephippium-bearing females were seen in the North Uist and Benbecula lochs during this period.

In the small, fertile island of Lismore the waters contain an abundance of lime salts, and the margins of the lakes have a rich molluscan fauna. The lochs (Baile a' Ghobhainn, Fiart, and Kilcheran), which are relatively deep, were examined 12th to 16th August 1904, when the temperature was high; Daphnia was apparently absent altogether from Loch Fiart, and in the other two lochs it had completely rounded head with no trace of galeation either in adults or in young forms (see Plate XIII. fig. 3). The head is of characteristic shape, the ventral margin being quite straight; this corresponds fairly well with the *Daphnia hyalina*, forma *typica*, of Leydig. In Loch Baile a' Ghobhainn ephippium-bearing females were found.

In the island of Mull, two lochs (Bà and Frisa), both rather deep, were examined on 16th and 17th August 1904. Daphnia was absent from Loch Bà; in Loch Frisa, the temperature being 59°·1 Fahr., the oldest Daphnias had round heads, other adults had slight galeation, the middle-aged Daphnias were definitely galeate, and the very youngest had completely rounded heads. They were on the whole very like the North Uist or Lewis forms.

The Orkney Islands were visited 15th to 27th August 1903, when Daphnias were abundant in all the lochs examined. An Orkney Daphnia is very distinct from any so far considered, being considerably larger, and the head being of a very characteristic shape. The young are slightly peaked, have long posterior spines, and, though somewhat larger, they are in general shape much like the young of Lewis. The middle-aged Daphnia is stouter, the head is relatively larger and more galeate, and the posterior spine is already considerably reduced in length; the adults are very large and stout, the posterior spine is reduced to a thickened stump, brown in colour, and the large head, which is slightly peaked, protrudes excessively inferior to the eye. The adult carries about nine summer eggs. Sometimes the reduction of the galea in the adult is complete; in one loch, Loch Kirbister, galeation in the younger forms is but slight, whilst in Loch Harray there seems to be no attempt at galeation. In this latter case, however, the Daphnias were forming ephippia; unlike those from the other Orkney lochs, the posterior spine showed no tendency to reduction, and on the whole there was a greater resemblance to the Shetland forms than to the typical Orkney Daphnia.

Some of these Orkney lochs were visited again three years later (August 1906), and exactly the same type of Daphnia was found, so that this is evidently a permanent form, at any rate so far as the summer months are concerned.

The total length of a typical adult from an Orkney loch is 2·75 mm. (including the stumpy spine). These Daphnias are quite the largest I have seen; the Shetland forms are longer, as the spine is not so much reduced, but otherwise they are not so bulky as the Orkney Daphnias. Mr T. Scott[1] has observed individuals as long as 3·4 mm. in Loch Oich, but these had a long galea and a moderate posterior spine.

The Shetland Islands were visited 30th June to 8th August 1903, when Daphnia was abundant. In these lochs there was no trace whatever of galeation, and in all stages the rounded head was unusually large; they are quite distinct from the obtusifrons and microcephalic forms of Lewis. The young have posterior spines which are as long as the body, not including the head; the posterior spine undergoes gradual reduction until in the adult it may become only one-eighth or one-tenth of the body-length. Such short spines

[1] *Seventeenth Annual Report, Fishery Board for Scotland*, Part III. p. 196, 1899.

are thick and brown, but not stumpy like those of the Orkney Islands. The adults have large eyes, they bear five or even as many as nine summer eggs, and the total length, including the spine, is about 2·8 mm. In general, it seems to be most nearly allied to the var. *rosea*, Sars, but differs in the absence of coloration. In several lochs males were abundant; they looked very like the younger females, and the spine was not at all reduced. Males were taken in Loch Spiggie, 4th July 1903; Loch Littlester, 7th August 1903; Loch Cliff, 4th August 1903; Loch Clousta, 12th July 1903; and Loch Vaara, 13th July 1903; ephippia were seen in Loch Littlester.

As regards the formation of ephippia and the occurrence of males, these seem to be rather uncommon phenomena in the Scottish lakes during the autumn months. They have been seen in the five Shetland lochs above mentioned, 4th July to 7th August 1903; in Loch Baile a' Ghobhainn, 13th August 1904; in Loch Ness, 29th August 1903, also 6th October 1898; in Loch Oich, 7th October 1898; in Loch a' Mhuilinn, near Fort Augustus, 27th August 1903; in Loch an Lagain, 25th September 1902; in Loch an Tuirc, 14th September 1902; in Loch Maol a' Choire, 13th September 1902; in Loch More (Caithness), October 1903; in Loch Harray, 22nd August 1903; and in Loch Fadagoa, 9th August 1903; but as these few records are all we know of from some hundreds of lochs examined during the summer and autumn months, we must suppose that, if ephippial formation is a normal function in the life-history of a Daphnia, it must take place in the winter months, and in fact Mr T. Scott found them frequently in December.

In the lochs of Shetland, then, they occur several months earlier. So far as our records go, ephippial formation never occurs in the lakes of the Highland region earlier than August; but, curiously enough, ephippium-bearing Daphnias were taken in Edgelaw Reservoir (near Edinburgh) as early as 7th July 1903, and, according to Mr Scott, in Duddingston Loch (Edinburgh) on 15th June 1898, in which loch also they were found on 16th September 1898 and also on 15th December 1897, and in Forfar Loch on 16th June 1898, and again on 15th September 1898.

But the lochs just mentioned are of small size, and being comparatively shallow the plankton fauna is subject to the extremes of temperature conditions and perhaps even to partial desiccation; in such an environment the ephippial function becomes more important than in the large lochs where more uniform conditions prevail.

Bosmina obtusirostris, Sars.—The plankton *Bosmina* in all the areas belonged to the species *B. obtusirostris*, Sars; in no case have I met with *B. longirostris*, and only once *B. longispina*, Fr. Leydig.

The *Bosmina obtusirostris* varied somewhat in size and general shape, but still I think all the different forms should be included under this species s. str. A very variable character is the length of the mucrones; usually the mucro is long in the young individuals, and with age it becomes shorter and shorter, in some few cases almost disappearing in the adults. Often the long mucro of the young is notched ventrally (see Plate XIV. fig. 9), but at every moult the notching becomes less marked, and in the adult there is usually no trace of such notches, though occasionally they persist; on the other hand, many long-spined young have no indication of notching. On examining the late embryos while still within the brood-pouch, we find that there the mucro reaches its highest development, relatively at any rate, and there too the notching is most conspicuous; in such embryos the mucrones function as hooks for keeping the shell valves approximated, the two hooks crossing each other, either hook folding over the opposite valve (see Plate XIV. fig. 15). And I suspect that the notching of the mucro has some reference to the same function. Now, seeing that the mucro of the adult *Bosmina obtusirostris* varies considerably in length in the various lochs, and is frequently much reduced in size with age, we may suppose that it serves no very important function in the adult, and it seems probable that the above-mentioned is one of its chief functions, though doubtless the long mucrones of the young are useful as balancing organs.

In the island of Lewis, *Bosmina obtusirostris* is usually abundant in any loch. The adult is of large size, sometimes almost 1 mm. long, the mucro included; the dorsal contour is rounded, the body is relatively high, the post-dorsal angle is obtuse, sometimes so much so that it almost disappears, the brow is protruding, the eye rather large, the rostrum is short and straight, the mucro is short, and the series of spines on the abdominal claw includes nine or ten spines. In the young, however, the body is relatively much more elongated, the posterior half of the dorsal contour is straight, the post-dorsal angle is less obtuse, the brow is not prominent, the rostrum is curved and long, the mucro is long, and the abdominal claw has only about four or five spines. Such is the Bosmina of Loch a' Chlachain (Plate XIV. fig. 11), Loch Bodavat, and others.

In other lochs of Lewis (Langavat, Trealaval, Skebacleit, etc.) we have very much the same form, differing, however, in that the rostrum is still shorter, but the mucro is long; in the newly hatched young the long mucrones are notched, and the notching persists even in the adult specimens, though it is not very marked. Between the forms with short mucro and those with long mucro there is every grade of intermediate.

In Loch Scaslavat the Bosmina was small, and it had a purple coloration; it belongs to the same variety, however, as the above.

In Loch Suainaval, the deepest loch of Lewis, and also in Loch Stacsavat, which receives water from Loch Suainaval, the Bosmina was quite different from that found elsewhere; it was rather larger, the mucro was very long, and so also was the rostrum; the adults carried as many as twelve eggs each. It agrees with *B. longispina*, var. *macrocerastes*, and is quite distinct from the long-spined forms of *B. obtusirostris*.

In North Uist and Benbecula the Bosmina was in general very like that of Lewis. In many lochs the adult specimens were somewhat more elongated and the rostrum longer than in the Lewis lochs, but here too in the very oldest forms it was found that the rostrum shortened and the curvature of the dorsal contour increased; further, with age the animal became more procumbent, in some few cases the mucro was much reduced—in Loch nan Geireann (Mill) the mucro was almost absent—but in most lochs it was of moderate size or long. The number of eggs carried by adults varied from two to seven. In some cases the head was almost as much depressed as in the var. *procumbens*.

In the island of Mull the Bosmina of Loch Bà was distinctly different from that of Loch Frisa. The adults of Loch Bà were small, rounded forms carrying only one egg; the dorsal contour was rounded, and the post-dorsal angle was quite absent, having merged in the curve of the back; the mucro was moderate-sized, the brow was not prominent, the rostrum was straight and of medium length. The young were more normal, being elongated, and having a definite post-dorsal angle (Plate XIV. figs. 5 and 6). On the other hand, the Bosmina of Loch Frisa was a larger form, the mucro was long, being occasionally though not usually serrated ventrally; it was very like the ordinary forms from Lewis or North Uist.

In the island of Lismore Bosmina was common in all three lochs. It belongs to exactly the same type as that of Lewis or North Uist. The young have rather longer spines than usual, and these are conspicuously notched, but the notching is not found on the small mucro of the adult Bosmina (Plate XIV. figs. 7, 8, 9, and 10).

In the Orkney and Shetland Islands Bosmina was rare; in very few lochs was it at all common. The adult was of much the same type throughout the two areas; it differs from that of Lewis mainly in size, being markedly smaller; also the adult carries fewer eggs, usually one only, sometimes two, and rarely as many as four; and further, the number of spines of the abdominal claw is always small, being only five. The young are elongated, the mucro is long, and the rostrum is long; the adult is relatively shorter, the mucro is invariably short, the rostrum is short, sometimes very short, the brow is prominent, and the eye moderate-sized or large. In sloughing specimens the reduction of the mucro and rostrum at the moult is plainly seen. This Bosmina is a small form of *B. obtusirostris*, s. str.

Ceratium hirundinella, Müller.—The Peridineæ are represented by various species in our lochs, the most abundant being *Ceratium hirundinella.* This organism varied very considerably even within the same area, and although on the whole the Shetland Ceratium was widely different from that of Lewis, these are not to be considered as distinct and fixed varieties, but probably as temporary adaptation forms; it would appear that the organism is exceedingly plastic, and its numerous forms are, I think, the expression of varying physical conditions, such as temperature.

In the small island of Lismore all three lochs (Fiart, Kilcheran, and Baile a' Ghobhainn) had this species in great abundance, but, curiously enough, the Ceratium of Loch Baile a' Ghobhainn was quite unlike that of Lochs Kilcheran and Fiart. The tow-nettings were taken at the same time (13th to 16th August 1904); the lochs are all moderately deep—over 20 feet in mean depth,—and the surface temperature was fairly high, being in Loch Baile a' Ghobhainn 62°·7 Fahr.; unfortunately, we have no record of the temperature of the other two lochs, but it is very unlikely that it could be appreciably lower than that of Loch Baile a' Ghobhainn, especially as the latter is larger and deeper. All the specimens of *Ceratium hirundinella* found in Loch Fiart and Loch Kilcheran were small, stumpy, and rather spinose; the fourth spine was either absent altogether, or only very slightly developed; the first spine was short, as also were the second and third, which, moreover, were either parallel or not much divergent (Plate XV. figs. 1 and 2). In Loch Baile a' Ghobhainn all the specimens were large; the spines were long and smooth, the fourth being usually quite as well developed as the third; the third and fourth spines were widely divergent from the second spine (Plate XV. fig. 3). I cannot give any explanation of these marked differences in lochs where the physical conditions were apparently identical.

In Loch Frisa (Mull), examined 17th August 1904, the surface temperature being 59°·1 Fahr., the Ceratium was much like that of Loch Fiart; there was some variation in the length of the fourth spine, but it was always short or nearly absent (Plate XV. figs. 4 and 5).

Ceratium hirundinella was rare in the lochs of North Uist and Benbecula, though it occurred in about half the lakes examined. On 9th May 1904, in Loch Skealtar, with a surface temperature of 47°·7 Fahr., the majority of the individuals were rather small; the spines were short, the fourth spine being ill developed or wanting; a few specimens were more slender, the fourth spine was present, and the second, third, and fourth spines were spreading, though not much so (Plate XV. fig. 13).

On 11th May 1904, in Loch nan Eun, with a surface temperature of 52° Fahr., the forms were rather large and slender, the second and third spines long and divergent, whilst the fourth spine was wanting or ill developed (Plate XV. fig. 12).

On 19th May 1904, in Loch nan Geireann (Mill), the surface temperature being 52° Fahr., the individuals were much like those of Loch Fiart.

On 24th May 1904, in Loch Scadavay, the species was comparatively large and slender; the first, second, and third spines (especially the first) were elongated, but the fourth spine was ill developed (Plate XV. fig. 16).

On 1st June 1904, in Loch Tormasad, at a temperature of 63°·0 Fahr., all the individuals were rather slender and long-spined; but whilst most had no fourth spine, others had a well-developed one.

On 3rd June 1904, in Loch Hunder, were rather large forms with elongated, wide-spreading arms, the fourth spine being moderately developed (Plate XV. fig. 11).

On 6th June 1904, in Loch a' Bharpa, Ceratium was much the same as in Loch Hunder.

On 18th June 1904, in Loch Hosta, the individuals were much like those of Loch Fiart.

On 25th June 1904, in Loch a' Ghlinne-Dorcha, the surface temperature being 55°·0 Fahr., the fourth spine was well developed, and the second, third, and fourth were wide-spreading and long.

On the same date, in Loch Crogavat, at a temperature of 55°·2 Fahr., the spines were long and slender, but the fourth spine was absent; the same kind occurred in Loch an Iasgaich on 9th June 1904, at a temperature of 66°·0 Fahr.

On 1st July 1904, in Loch Olavat (Benbecula), the individuals were rather small and the spines were short, though the fourth was moderately developed.

In the island of Lewis, *Ceratium hirundinella* was found in many lochs, but in no loch was it abundant.

On 29th June 1903, in Loch Raonasgail, with a surface temperature of 59°·0 Fahr., were found slender forms with elongated spines, but the fourth was ill developed.

On 17th July 1903, in Loch Langavat, the temperature being 56°·1 Fahr., all the spines were long, the fourth being fairly well developed, and the second, third, and fourth spines were widely divergent (Plate XV. fig. 10).

On 1st August 1903, in Loch Bodavat, the surface temperature being 60°·0 Fahr., the individuals were large; all the spines were slender and elongated, the fourth spine being as well developed as the third, and the second, third, and fourth spines were widely divergent. In this loch *Ceratium hirundinella* reached the furthest limit of its development (Plate XV. fig. 6).

On 12th August 1903, in Loch Skebacleit, the fourth spine was ill developed, but the second and third spines were long and diverging.

On 14th August 1903, in Loch nan Deaspoirt, the surface temperature being 58°·0 Fahr., all the specimens seen were rather small, and the fourth spine was ill developed (Plate XV. fig. 9).

On the same date, in Loch Dhomhnuill Bhig, were found comparatively slender forms with well-developed fourth spine; the surface of the organism was somewhat prickly (Plate XV. fig. 7).

On 15th August 1903, in Loch Valtos, the Ceratium was much the same as in Loch Dhomhnuill Bhig.

In the lochs of the Orkney and Shetland Islands *Ceratium hirundinella* was very abundant.

Orkney.—On 15th August 1903, in Loch Kirbister, with a surface temperature of 57°·0 Fahr., the individuals were small, the fourth spine was moderately developed, and the other spines were rather short.

On 22nd August 1903, in Loch Harray, the surface temperature being 55°·0 Fahr., the fourth spine was always present, though small; the other spines were reduced in length, sometimes considerably so, as in Plate XV. fig. 18.

On 27th August 1903, in Loch Hundland, the surface temperature being 62° Fahr., some specimens were like those of Lewis, the third and fourth spines being fairly well developed and diverging rather widely; other specimens had no fourth or only a very small one, whilst all the other spines were fairly long (Plate XV. figs. 24 and 25).

Shetland.—Here the individuals were always small, the spines short, and the body surface coarsely reticulate.

On 2nd July 1903, in Loch Tingwall, the surface temperature being 55°·3 Fahr., the second spine was fairly long, but all the others were relatively short, the fourth being almost absent (Plate XV. fig. 20).

On 4th July 1903, in Loch Spiggie, the surface temperature being 56°·8 Fahr., the fourth spine was usually absent, and all the other spines were short; in general shape the organism was stumpy, its central body being large (Plate XV. fig. 19).

On 5th July 1903, in Loch Brow, the Ceratium was very like that of Loch Tingwall; many specimens had a small fourth spine.

On 14th July 1903, in Loch Collaster, with a surface temperature of 53°·0 Fahr., the fourth spine was small or absent, the second spine was long, but the third spine was short (Plate XV. fig. 22).

On 15th July 1903, in Grass Water, the fourth spine was absent, the second and third spines were parallel, the second being long.

On 17th July 1903, in Clings Water, the surface temperature being 54°·8 Fahr., there was much the same kind of Ceratium as that in Grass Water (Plate XV. fig. 23).

On 24th July 1903, in Loch Burraland, the fourth spine was absent and all the other spines were comparatively short; the body was relatively large and coarsely reticulate.

On 4th August 1903, in Loch Cliff, the surface temperature being 56°·3 Fahr., the fourth spine was absent, and the second and third spines were small.

On 6th August 1903, in Loch Snarravoe, the fourth spine was always present, though small; all the other spines were somewhat reduced, though not much so; on the whole, however, it can be described as a small and stumpy form.

The interpretation of the extreme variability of *Ceratium hirundinella* from different lochs is not very obvious, though doubtless the temperature is an important causative factor. That this variation is not erratic, but has some relation to the physical conditions of the environment, is shown by the fact that in the Shetland Islands, where the temperature and other conditions are fairly uniform, the Ceratium is all of one type; moreover, generally speaking, all the individuals of any loch in any of the areas are either identical or they differ but slightly amongst themselves, and we do not find the two extremes in any one loch, though they do sometimes occur in different lochs of the same neighbourhood.

We have seen that in the Shetland Islands the organism was always small, stumpy, and coarsely reticulated, the spines short, and the fourth spine absent or small; in the Lewis lochs, on the other hand, we found a larger and more slender form, the spines were long, the fourth spine being sometimes as well developed as the third. And considering only the North Uist and Benbecula lochs, it was usual to find in the lakes of late spring a small short-spined form with no fourth spine or only a very small one, whilst in summer, when the waters were warmer, the Ceratium was of a large and slender type. And as I have already mentioned, the Shetland lochs were on the whole colder than those of Lewis, so that quite possibly the differences between the extreme forms are consequent on the difference in thermal conditions.

Nevertheless, I cannot think that this is the whole explanation of the difference, for in a number of cases—*e.g.* Loch Langavat (Lewis), 17th July 1903, surface temperature 56°·1; Loch a' Ghlinne-Dorcha (North Uist), 25th June 1904, surface temperature 55°·0 Fahr.; Loch Crogavat (North Uist), 25th June 1904, surface temperature 55°·2

Fahr.; and Loch nan Eun (North Uist), 11th May 1904, surface temperature 52°·0 Fahr.—the Lewis and North Uist lochs, at a temperature practically identical with that of the Shetland lochs, had the large and slender form of Ceratium. And as regards the development of a fourth spine, it is largest when the temperature is high, and generally speaking its development progresses simultaneously with the elongation and divergence of the second and third spines; and yet in a number of cases—*e.g.* Loch Raonasgail (Lewis), Loch an Iasgaich (North Uist)—in lochs at a high summer temperature the fourth spine was very ill developed, though the other spines were long and the organism large and slender; and again, in the small stumpy forms of some Shetland and Orkney lochs the fourth spine was relatively well developed, and was actually larger than that in some of the slender-formed Ceratiums of Lewis and North Uist (compare Lochs Kirbister and Harray with Lochs nan Deaspoirt and nan Eun).

It may be that the Ceratiums of each loch in any area whatsoever will vary according to the temperature of the water, becoming large and slender and four-spined if the summer temperature be high enough, and small, stumpy, and three-spined in winter, and that the differences of form in lochs of like thermal conditions are due to a varying sensitiveness of the species, or to the presence of some unknown restraining factor in varying degree.

EXPLANATION OF THE FIGURES

Plate X

Fig. 1. Juvenile Daphnia from Loch Raoinavat (Lewis).
Fig. 2. Adult „ „ „ „
Fig. 3. „ „ „ Valtos „
Fig. 4. Juvenile „ „ „ „
Fig. 5. Late embryo of a Loch Valtos Daphnia.
Fig. 6. Young Daphnia from Loch na Craobhaig (Lewis).
Fig. 7. Older „ „ „ „
Fig. 8. Egg-bearing Daphnia from Loch a' Chlachain (Lewis).
Fig. 9. „ „ „ „ nan Deaspoirt (Lewis).
Fig. 10. Microcephalic adult from Loch Fadagoa (Lewis).

Plate XI

Fig. 1. Juvenile Daphnia from Loch an Tomain (North Uist).
Fig. 2. Egg-bearing Daphnia from Loch an Tomain (North Uist).
Fig. 3. Juvenile Daphnia from Loch an Iasgaich (North Uist).
Fig. 4. Egg-bearing form from Loch Olavat (Benbecula).
Fig. 5. Adult Daphnia of Loch Vieragvat (North Uist).
Fig. 6. Juvenile Daphnia of Loch Vieragvat „
Fig. 7. „ „ „ Skealtar „

Plate XII

Fig. 1. Juvenile Daphnia from Loch Boardhouse (Orkney).
Fig. 2. Older ,, ,, ,, ,,
Fig. 3. Adult ,, ,, ,, ,,
Fig. 4. ,, ,, ,, Burraland (Shetland).
Figs. 5 and 6. Juvenile Daphnias from Loch Snarravoe (Shetland).
Fig. 7. Head of adult Daphnia ,, ,, ,, ,,

Plate XIII

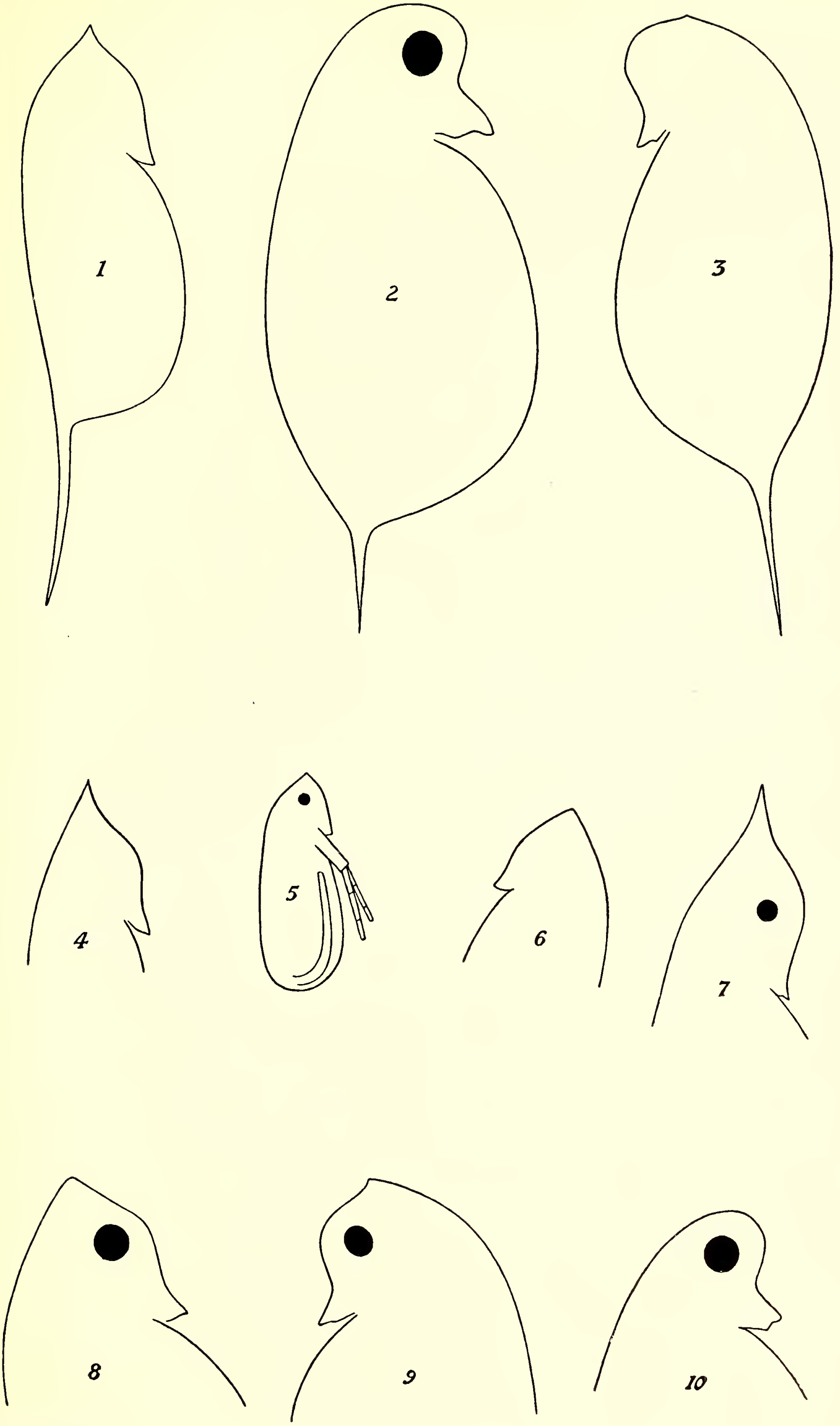
Fig. 1. Head of a sloughing Daphnia in Loch Frisa (Mull).
Fig. 2. Juvenile Daphnia of Loch Frisa (Mull).
Fig. 3. Adult ,, ,, Kilcheran (Lismore).
Fig. 4. Bosmina of Loch a' Chonnachair (North Uist), a procumbent form.
Fig. 5. Bosmina from Loch nan Aùscot (Benbecula).
Fig. 6. ,, of Loch Skealtar (North Uist). Note the large eye and the protruding brow.

Plate XIV

Fig. 1. Bosmina of Loch Brough (Shetland).
Fig. 2. ,, Clubbi Shuns (Shetland).
Fig. 3. Young Bosmina of Loch Tingwall (Shetland).
Fig. 4. Bosmina (old) of Loch Clickhimin ,,
Fig. 5. ,, of Loch Bà (Mull).
Fig. 6. Juvenile Bosmina of Loch Bà (Mull).
Fig. 7. Bosmina of Loch Fiart (Lismore).
Fig. 8. ,, (juvenile) of Loch Fiart (Lismore).
Fig. 9. Notched mucro of same.
Fig. 10. Late embryo of a Loch Fiart Bosmina.
Fig. 11. Bosmina from Loch a' Chlachain (Lewis).
Fig. 12. ,, ,, ,, Langavat ,,
Fig. 13. Juvenile Bosmina from Loch Suainaval (Lewis).
Fig. 14. Adult ,, ,, ,, ,,
Fig. 15. The crossed mucrones in a late embryo from Loch nan Geireann (Mill) (North Uist).
Fig. 16. End of abdomen of Bosmina from Loch Bà (Mull). The specimen was sloughing, and the newly formed row of spines is out of position as a result of post-mortem retraction.
Fig. 17. End of abdomen of Bosmina from Loch Stacsavat (Lewis).

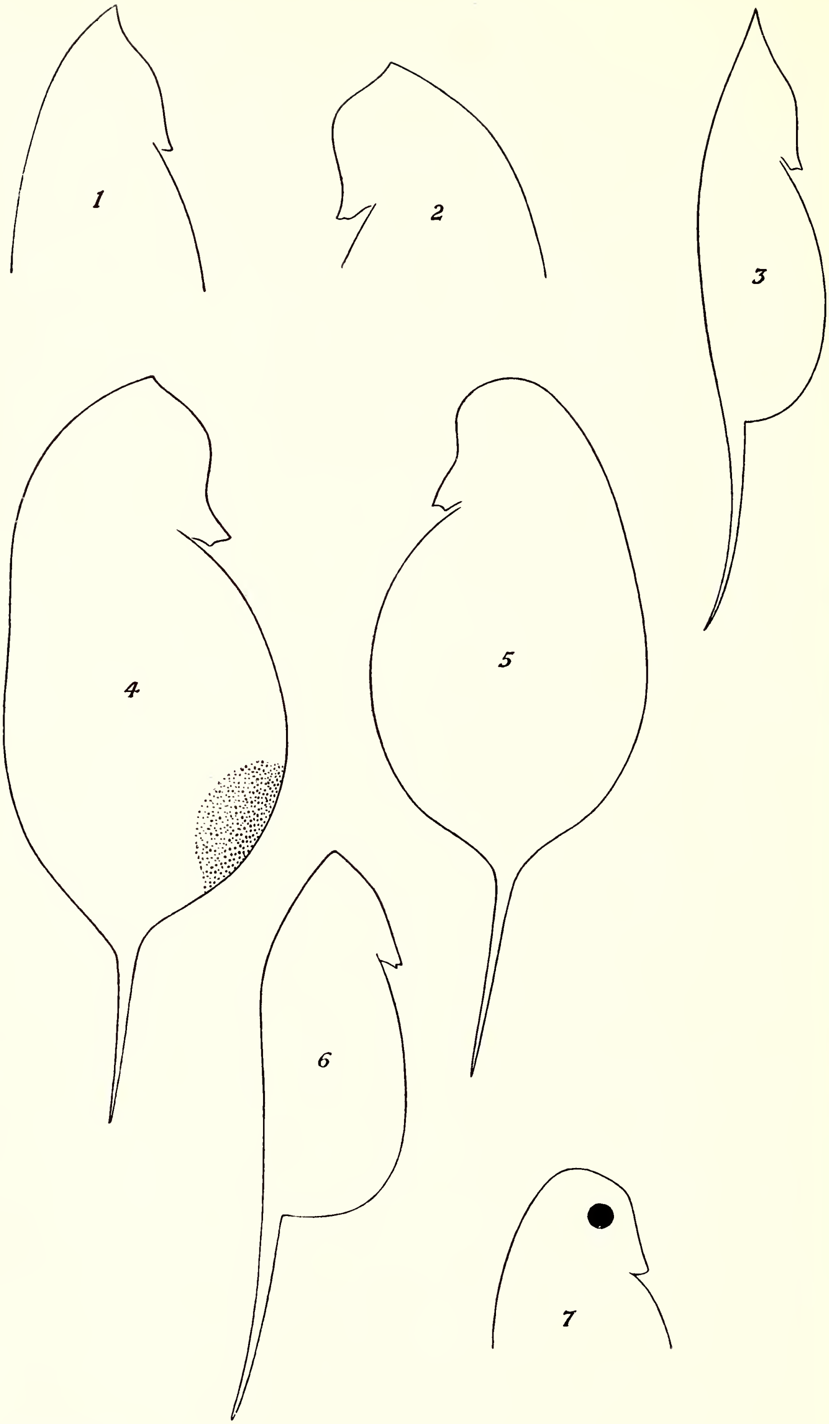
Plate XV

Figs. 1 and 2. Ceratium from Loch Fiart (Lismore).
Fig. 3. Ceratium from Loch Baile a' Ghobhainn (Lismore).



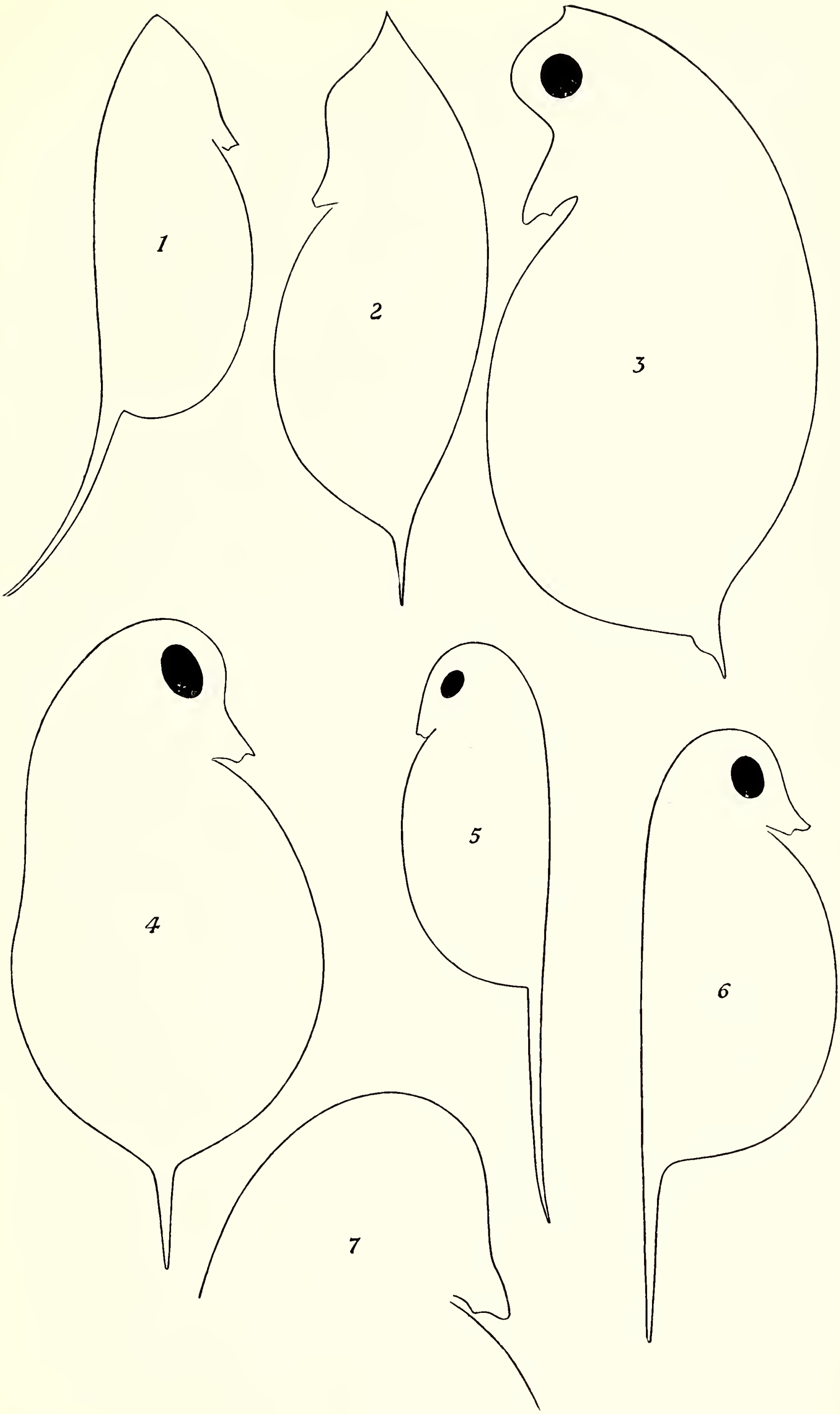
John Hewitt.

DAPHNIA IN THE LOCHS OF LEWIS.



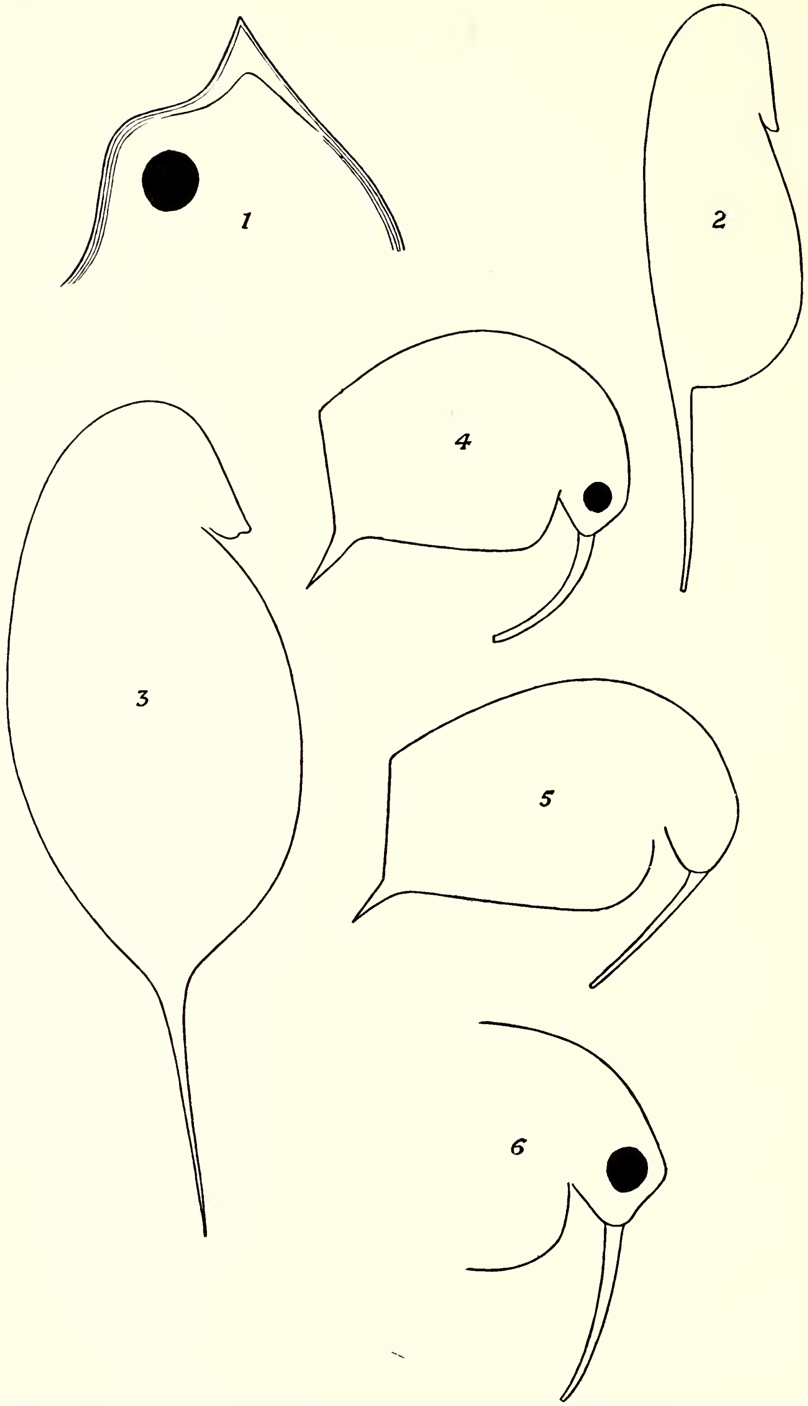
John Hewitt.

Daphnia in the Lochs of North Uist and Benbecula.



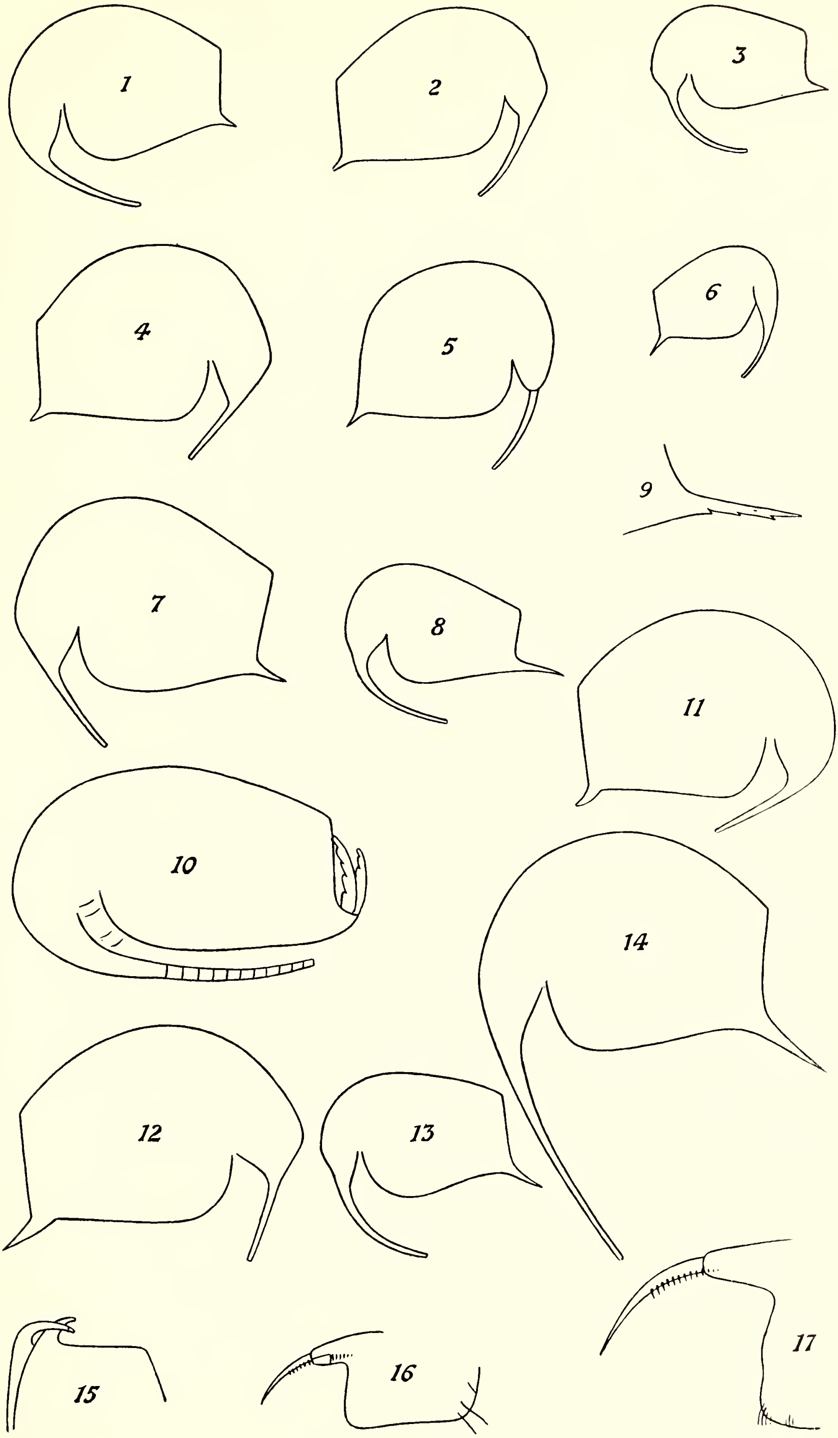
John Hewitt.

DAPHNIA IN THE LOCHS OF ORKNEY AND SHETLAND.



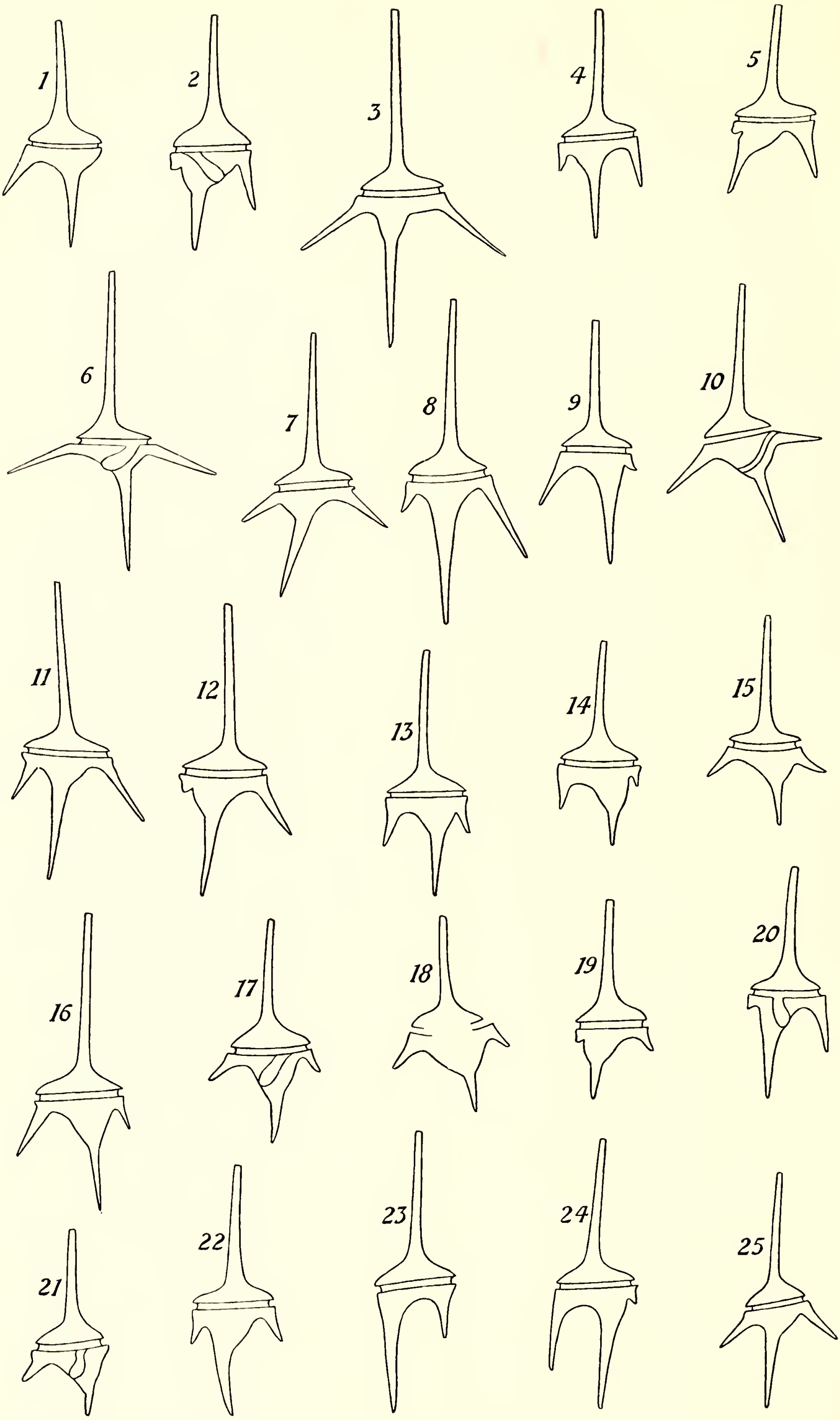
John Hewitt.

DAPHNIA AND BOSMINA IN THE LOCHS OF MULL, LISMORE, AND NORTH UIST.



John Hewitt.

Bosmina in the Lochs of Shetland, Mull, Lismore, Lewis, and North Uist.



John Hewitt.

Ceratium in the Lochs of Lismore, Mull, Lewis, North Uist, Benbecula, Orkney, and Shetland.

Figs. 4 and 5. Ceratium from Loch Frisa (Mull).
Fig. 6. Ceratium from Loch Bodavat (Lewis).
Fig. 7. ,, ,, ,, Dhomhnuill Bhig (Lewis).
Fig. 8. ,, ,, ,, Raonasgail (Lewis).
Fig. 9. ,, ,, ,, nan Deaspoirt (Lewis).
Fig. 10. ,, ,, ,, Langavat (Lewis).
Fig. 11. ,, ,, ,, Hunder (North Uist).
Fig. 12. ,, ,, ,, nan Eun ,,
Fig. 13. ,, ,, ,, Skealtar ,,
Fig. 14. ,, ,, ,, Hosta ,,
Fig. 15. ,, ,, ,, Olavat (Benbecula).
Fig. 16. ,, ,, ,, Scadavay (North Uist).
Fig. 17. ,, ,, ,, Kirbister (Orkney).
Fig. 18. ,, ,, ,, Harray ,,
Fig. 19. ,, ,, ,, Spiggie (Shetland).
Fig. 20. ,, ,, ,, Tingwall ,,
Fig. 21. ,, ,, ,, Cliff ,,
Fig. 22. ,, ,, ,, Collaster ,,
Fig. 23. ,, ,, Clings Water (Shetland).
Figs. 24 and 25. Ceratium from Loch Hundland (Orkney).

ON THE NATURE AND ORIGIN OF FRESH-WATER ORGANISMS

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It is a well-known fact that the forms of life found in fresh water are usually very different from those found in the sea. Everyone is aware that carp live in fresh water, and that bladder-wrack is to be found on our coasts, and not in rivers and ponds. But the matter goes further than this, and a more detailed study shows that there is quite a large number of forms perfectly characteristic of fresh water and not occurring in the sea, while another series is equally distinctive of the ocean and unknown in the fresh waters of the globe. It will perhaps be well to consider first the animals (fauna), and afterwards the plants (flora), of these two great divisions of aquatic life.

When we study the general characters of a normal fresh-water fauna, and contrast them with those of a marine fauna, we soon become aware of an overwhelming preponderance of species in the ocean.[1] That is not to say that the waters of rivers and lakes are not well stocked, but that they are stocked by a far smaller number of different forms, which is not surprising when we consider the insignificant total extent of fresh water, compared with the vast size of the ocean.

Amongst the Vertebrata proper, it is principally the fishes which have retained an aquatic mode of life. Excluding the wading and diving birds, we have a few truly aquatic mammals and reptiles, which have undoubtedly acquired this habit of living secondarily. The Amphibia, mainly aquatic in early life, are mostly terrestrial in their adult state, but, as far as they inhabit water at all, live in fresh water and never in salt. Coming to the fishes, then, we find that the great majority of the known species are inhabitants of the sea, the extensive group of the Elasmobranchs being almost entirely

[1] *Cf.* Quinton, "L'eau de Mer Milieu organique," Paris, 1904. The author contrasts (p. 55 *et seq.*) the orders, etc., represented in the sea, with those known to occur in fresh water.

marine. On the other hand, the small but interesting group of lung-fishes (Dipnoi) is wholly fluviatile, while many Teleostean fishes are common inhabitants of our rivers and lakes.

Descending in the scale, we find both the Tunicates and *Amphioxus* unknown save in the sea.

Among the Arthropoda we find examples of both typical fresh-water and typical marine forms. The insects, myriapods and arachnids, are mainly terrestrial animals, but nevertheless a number of adult insects, and a still larger number of insect larvæ, are inhabitants of ponds and streams, while the family of the Hydrachnidæ is almost entirely confined to fresh water. The Crustacea, being principally aquatic, afford examples of both groups. Of the lower forms, the Cirripedia are entirely marine; the Copepoda and Ostracoda are abundant both in the sea and in fresh water, though present in greater variety in the sea; and the Branchiopoda are most common in fresh water. The great majority of the higher Crustacea are marine, the Cumacea and Stomatopoda exclusively so, and the other groups to a very large extent. The Isopoda, however, together with a number of terrestrial forms, includes the characteristic fresh-water genus *Asellus*; in like manner the genus *Gammarus*, species of which are common in fresh water, occurs amongst the Amphipoda. The Decapoda too, in addition to a great many marine types, contains the crayfishes, *Astacus* and its allies, certain prawns (*Palæmon*, *Caridina*, etc.) and crabs (principally Potamonidæ), which are characteristic of fresh water.

All the Brachiopoda are marine, and so are most of the Polyzoa, although the sub-group of the Phylactolæmata is confined to fresh water. Turning to the Mollusca, we find a number of types belonging both to the Gasteropoda and to the Lamellibranchiata which are well known in, and characteristic of, various fresh waters, though these divisions have a much larger number of species in the sea. Amongst others, we may indicate *Planorbis*, *Limnæa*, *Paludina*, and *Unio* from fresh water, and *Buccinum*, *Trochus*, *Patella*, and *Cardium* from the ocean, as being typical genera belonging to the two groups. The Cephalopoda are found only in the ocean.

A considerable number of what we may popularly call "worms" are internal parasites, and so fall outside the scope of our inquiry. Of more highly organised forms, the Polychæta are all but entirely marine, while the Oligochæta, with a few marine and many terrestrial types, yet includes a number (such as *Nais* and *Tubifex*) which are characteristic of fresh water. The leeches are for the most part terrestrial and fresh-water, though some forms inhabit the sea; and the Nemertinea, on the other hand, are principally marine forms, although a few are known from fresh water. Amongst the flat-worms we find a number of Turbellaria (such as *Planaria*), which are common inhabitants of ponds and streams, but many other genera are terrestrial or marine.

The small group of the Rotifera is an overwhelmingly fresh-water one, there being, however, some species found in brackish water, and a few which are marine.

In the case of the Echinodermata, we have a striking example of a very large assemblage of forms, not one of which, so far as we know, exists outside the sea. It is, in fact, the only instance of a really large group confined to one medium without a single exception, and it has a special interest accordingly.

With very few exceptions, the phylum Cœlenterata is similarly marine. In the subdivision Hydrozoa alone, a very few forms inhabit fresh water, the most important being *Hydra* and *Cordylophora*. Thus, as in the majority of cases we have considered, there are certain exceptional forms which are sufficient to disprove any general statement as to habitat.

The sponges are almost as strikingly salt-water forms as are the Cœlenterata. Out of some fifty known families, a single sub-family only has fresh-water representatives, but the principal fresh-water genus—*Spongilla*—is widely distributed in the rivers and lakes of most parts of the world.

Amongst the simplest forms of life, the Protozoa, we find a number of organisms which are familiar objects in fresh water, and yet the majority live in the sea, where they play a very important rôle. Most of those in the sub-groups Lobosa (including *Amœba* and *Difflugia*) and Heliozoa (*Actinosphærium*, etc.) have a fresh-water habitat; but the Foraminifera are overwhelmingly marine, and the Radiolaria entirely so. Finally, the Ciliata, with forms such as *Vorticella* and *Paramœcium*, is a sub-group well represented in fresh water, and so is the Flagellata, with *Euglena*; but both of these contain also a considerable number of marine types.

It will now be evident that we know of some aquatic forms which are usually absent from the ocean, in addition to others which are seldom or never found in fresh water, and it may be well to enumerate again the most striking examples. In the sea we do not find Amphibia, Dipnoi, or phylactolæmatous Polyzoa. Further, there are in the ocean comparatively few insects and insect larvæ, Hydrachnidæ, Branchiopoda, Oligochæta, leeches, and Rotifers. On the other hand, the following groups do not live in fresh water: Cephalochordata, Tunicata, Cirripedia, Cumacea, Stomatopoda, Brachiopoda, Cephalopoda, Polychæta, and Echinodermata. Besides these, the Elasmobranchs, Decapod Crustacea, Nemertinea, Cœlenterata, and sponges are only poorly represented apart from the sea.

Although an overwhelming majority of salt-water species is characteristic in the case of animals, this is not so in the case of plants. It is difficult to be very precise in a matter which involves the counting up of an immense number of aquatic species, but there seems some evidence for believing that the number of fresh-water forms is actually in excess of those which inhabit the sea. Be this as it may, we can safely state that there is no such striking disproportion as certainly exists in the animal kingdom, and that the waters of the globe, both salt and fresh, are inhabited by very many forms of vegetable life.

Of the higher plants, a large proportion of the Phanerogams are purely terrestrial; but, with the exception of the Gymnospermæ (among which, however, swamp-plants occur), most of the larger groups contain species of aquatic habitat. The marine flora includes comparatively few Phanerogams, which belong to the families Hydrocharitaceæ and Potamogetonaceæ, the so-called sea-grass (*Zostera marina*) being a very common and widely distributed example. There are no marine Dicotylæ. The Phanerogams of fresh water, on the contrary, belong to the most diverse orders of Angiosperms, and far exceed in number of species those of salt water. Of importance amongst the Dicotylæ are the Nymphæaceæ, all fresh-water forms; certain Ranunculaceæ (*Batrachium*); Ceratophyllaceæ; Halorhagidaceæ (*Myriophyllum*); and Utriculariaceæ. Of Monocotylæ we may mention the following families:—Alismaceæ; Potamogetonaceæ (with *Potamogeton natans*); Naiadaceæ; and Lemnaceæ.

It is amongst the Cryptogams, however, that we find the number of aquatic forms really great. Nevertheless, the Pteridophyta and Bryophyta are of little importance, for both of these groups are entirely unrepresented in the sea, although a few examples are known from fresh water. Of Pteridophyta, various Salviniaceæ (*Salvinia* and *Azolla*), Marsiliaceæ, and Isoetaceæ (*Isoetes lacustris*) occur in fresh water, and of Bryophyta a rather larger assemblage, among which we may mention *Riccia fluitans*, *Fontinalis antipyretica*, *Hypnum*, and *Sphagnum*.

The Thallophyta, then, constitutes the great proportion of both salt- and fresh-water plants, but the classes differ markedly in their distribution between the two media. The Characeæ, with the well-known genera *Chara* and *Nitella*, are exclusively fresh-water forms. Both the Phæophyceæ and Rhodophyceæ, on the other hand, are very widely distributed, and are represented by many species in the sea, while in fresh water there occur only a few isolated examples. Among the most important of these Algæ we may indicate the genera *Laminaria*, *Fucus*, *Sargassum*, and *Chondrus* from the ocean, and *Batrachospermum* from fresh water.

The importance of the class Chlorophyceæ is much greater in fresh water than in salt. The whole of the order Conjugatæ, including the unicellular Desmidiaceæ, is confined to fresh water, in which there are no more characteristic types than such as *Spirogyra*, *Zygnema*, *Cosmarium*, *Staurastrum*, *Micrasterias*, and *Xanthidium*. Other characteristic fresh-water Chlorophyceæ belong to the genera *Scenedesmus*, *Pediastrum*, *Oedogonium*, *Cladophora*, and *Vaucheria*. Familiar marine forms are *Ulva*, *Caulerpa*, and a species of *Cladophora*.

The two groups Diatomaceæ and Peridineæ together furnish the main mass of the vegetable plankton in the sea, but while the Diatoms are also of some importance in fresh water, the Peridineæ are represented by comparatively few forms. Among the latter, mention may be made of a cosmopolitan fresh-water type, in *Ceratium hirundinella*.

The Myxophyceæ and Bacteria are both more generally distributed in fresh water than in salt. Of the former, the Oscillatoriaceæ are represented in the sea, and certain Bacteria are abundant in shallow water near the coast. Still, these two groups are more prominent in fresh water, both as regards the number of forms and the number of individuals, there being among the Myxophyceæ several genera (*Oscillatoria*, *Gomphosphæria*, *Clathrocystis*, *Anabæna*), species of which may appear in such quantities in lakes as to produce the phenomenon known as "water-bloom."

We may now, as in the case of the animal kingdom, briefly gather together the most striking points in the distribution of fresh- and salt-water plants. In the sea we find no Dicotylæ, Pteridophyta, Bryophyta, Characeæ, or Conjugatæ, and only comparatively few Monocotylæ. In fresh water there are no groups containing aquatic plants which are quite unrepresented, but the Peridineæ occur only to a limited extent, and the Phæophyceæ and Rhodophyceæ in very small numbers.

By our rather detailed examination of the organisms of fresh and salt waters, it has become clear that there is a very definite series of forms perfectly characteristic of the one medium or of the other. There are, however, some striking cases known, which would seem at first sight to entirely disprove this statement. The Caspian Sea, in spite of its name, is in some regions, and particularly in the surface layers, less than one-fifth as salt [1] as the ocean, and thus may almost be considered a fresh-water basin. Yet the fauna includes many forms which we cannot but regard as typically marine. In addition to characteristic fresh-water animals (*Silurus*, *Cyprinus*, *Astacus*), we

[1] Quinton, *op. cit.*, p. 215.

find a seal, a herring, certain Cumacea and Schizopoda, the mollusc *Cardium edule*, a Polychæte worm, and two Foraminifera of marine type. Lake Baikal, in Eastern Siberia, which is one of the largest fresh-water lakes in the world, is similarly inhabited by a seal, also by certain Harpacticoid Copepods and a Polychæte worm.

It is no wonder, then, that cases such as these, in which sea-organisms are living in fresh-water basins, have aroused wide interest. An inquiry into the past history of these inland seas affords some clue (particularly in the case of the Caspian) as to the meaning of the anomalies. During the early part of the Tertiary period, the Caspian appears to have belonged to a great sea which then covered the southern part of Russia, and was in direct communication with the ocean. Only since then has it become gradually cut off from the sea and gradually freshened. If this is indeed the case, it is not difficult to believe that the marine forms which have been mentioned are forms which have persisted in the lake since it was actually a portion of the ocean.

Inland basins which seem to be the modified remainders of isolated portions of the ocean are sometimes spoken of as relict seas (*Reliktenseen*), and the Caspian is manifestly an example of such. The case of Lake Baikal is by no means so satisfactorily proved from a geological point of view; but however that may be, it is clear that in certain instances, at any rate, the existence of what we have called marine animal types in fresh water is merely an indication of the origin of that fresh-water basin, and not of a lack of distinctness between the two great groups of aquatic animals.

If, then, certain apparent exceptions do not really invalidate our conception of a difference between marine and fresh-water organisms, we of necessity ask the question: Why are certain forms present in one case and not in the other? This at once takes us to the root of matters, for it not only involves a study of organisms in relation to their environment, but suggests the additional question: How did fresh-water life originate?

At the present day, the most varied forms of life, both animal and vegetable, are found in fresh water. Representatives of most of the principal groups are known, from the Protozoa up to the mammals themselves, and from the lowest Algæ to the flowering plants. Yet there seems no escape from the conclusion that life had its origin in the ocean, and that all the fresh-water organisms with which we are acquainted must have been derived either directly or indirectly from that source.

Our study of the different groups concerned has shown that, while certain cases exist in which the forms all inhabit one medium or the other, in the greater number of cases some types are capable of existing in the sea and others in fresh water. This is in itself an indication that no very wide gulf is actually fixed between fresh-water and marine organisms, and that in point of fact, given suitable conditions, representatives of the most diverse classes have been able to accommodate themselves to life in a medium of greater or less density.

But we have direct evidence on this head in certain cases. The probable existence of relict seas has already been referred to, and they presuppose the survival of ocean forms in fresher water, although the gradual modification may have taken place in past geological time.

Yet there are instances known which seem clearly to show that the process of accommodation to a different medium still proceeds, and that quite a number of forms are capable of withstanding important changes in salinity. The hydroid polype *Cordylophora lacustris* was orginally discovered in brackish water ; it is common in the Norfolk Broads, where there is a considerable admixture of sea-water, and is known elsewhere as an estuarine form. Still, it has been able to migrate into entirely fresh water, for it has been found in the Seine near Paris, in the fresh-water tanks of the Jardin des Plantes, and has actually invaded the water-mains of the city of Hamburg.[1]

Another case which indicates the possibilities for an even more sensitive type, is that of *Crambessa tagi*, a large Discomedusan which commonly ascends the river Tagus until it reaches comparatively fresh water.[2]

A more extreme example, embracing animals from several groups, is afforded by the fauna of certain artificial ponds at Port Canning, Lower Bengal.[3] Situated in the neighbourhood of the Ganges delta, these ponds are sometimes in communication with the estuary, from which they have undoubtedly derived the marine forms which interest us. At other times, however, they are completely isolated, and may become even more strongly saline than the sea through continued evaporation, or during the rainy season may become nearly fresh. The most striking of the marine types referred to, which are capable of withstanding such profound changes in the nature of the water, are a sea-anemone (*Metridium*), a Hydromedusan with hydroid stage (*Irene*), a Cirripede (*Balanus*), a cheilostomatous Polyzoan (*Membranipora*), and a Polychæte worm.

Finally, there is an interesting account given by von Kennel[4] of the inhabitants of a lagoon on the east coast of Trinidad, which at times is flooded by the sea, and at other times becomes almost

[1] Semper, *The Natural Conditions of Existence as they affect Animal Life*, 5th ed., London, 1906, p. 152.

[2] Haeckel, *Zeitschr. f. wiss. Zool.*, Bd. xix., 1869, p. 509.

[3] Annandale, *Records Indian Museum*, vol. i., 1907, p. 35.

[4] *Arb. Zool. Inst. Würzburg*, Bd. vi., 1883, p. 276.

entirely fresh. Together with typical fresh-water types such as tadpoles and gnat larvæ, he found quite equally common a species of *Mysis*, a Polychæte worm (*Nereis* or nearly allied form), and a small Hydromedusan which he has named *Halmomises.* A striking feature of this case is that these truly marine types appear to flourish better in the fresher than in the brackish water, for in the latter only occasional specimens were found.

Additional facts recorded by von Kennel,[1] concerning the fauna of the river Ortoire in Trinidad, have special significance as indicating the manner in which a river may be directly colonised by animal forms from the sea. In the wide estuary of this slowly flowing river, the tide makes itself felt for miles above the mouth, and, having but a very languid current to contend against, is enabled to carry up certain marine animals, some of which, being capable of withstanding the increased freshness of the water, have settled down permanently at considerable distances from the sea. The following forms are mentioned as having been found more than eight miles from the river-mouth, apparently perfectly adapted to life in fresh water: a species of mussel (*Mytilus*), a species of *Pholas*, and a Polychæte worm.

Nor is there wanting certain experimental evidence on this question of change of medium. Beudant[2] experimented with a series of marine molluscs (he included the Cirripede *Balanus*), which he attempted to gradually accustom to living in fresh water. By a sufficiently slow addition of fresh water, he obtained at last a number of different forms living on, apparently uninjured, in water which was perfectly fresh, although other species had succumbed in the process. In the converse of this experiment, which consisted in accustoming fresh-water molluscs to water increasingly salt, very similar results were reached. It was thus abundantly proved that a number of molluscan species (and *Balanus*) could live undisturbed in either sea-water or fresh.

But while laying emphasis on the fact that the freshness has not prevented representatives of most diverse classes from colonising inland waters, we have intentionally disregarded certain cases in which this freshness does appear to constitute an impassable barrier. We know from experimental evidence, and we infer from cases like those in Bengal and Trinidad, that a number of animal types, at all events, are extremely sensitive to changes in salinity, and cannot survive more than a slight variation in this respect. Why this is so in some cases and not in others, we are rather at a loss to explain. Whether this character has been acquired by more specialised types, and not by lower and more generalised ones, we can only guess; but

[1] *Op. cit.*, p. 274.
[2] *Vide* Semper, *op. cit.*, p. 153.

we are fairly safe in saying that such sensitive forms must be restricted in their range, and are little likely to colonise fresh water.

The evidence which has been cited seems to suggest that our lists of fresh-water and salt-water forms, while indicating correctly the general tendencies of the groups in question, are liable to be modified, as exploration brings to light types which are adapted to a different state of existence. We are justified in saying that in most instances it is not really impossible for representatives of this or that group to exist in either fresh or salt water as the case may be, for increase of knowledge has repeatedly brought to light cases which are exceptions to the ideas previously held. Our proposition that fresh-water forms have been derived from the ocean is clearly supported by the evidence we have at our disposal, and a good deal of this concerns a transference from sea-water, as we now know it, to water which is brackish or fresh.

We have, however, no reason to suppose that the water of the ocean has always been just as saline as it is at present; indeed, we have every reason to believe that its salinity has been slowly increasing through countless ages, by the addition of salts dissolved out of the land-masses. Quinton has collected testimony to prove that, on the one hand, the sea of former epochs was essentially the same in chemical composition as that of to-day,[1] but that, on the other hand, the concentration of the salts in the water was very considerably less.[2] If, then, we know of organisms which have been able to accomplish a greater change in recent times, it is not hard to believe that many forms gradually achieved a lesser change during past geological ages.

A further discussion of this is not necessary here; but granting that the earliest known forms of life were inhabitants of the ocean, and that the non-salinity of rivers and lakes was, in most cases, no insuperable bar to colonisation, we have to look for other reasons which may explain why only certain forms (and a very small assemblage, in the case of animals) have succeeded in establishing themselves. There are, indeed, other factors which have had as great or even greater influence in hindering the migration into fresh water as the difference in salinity, and these we may proceed to enumerate.

In the front rank we may place the prevalence in the sea of delicate, feebly-swimming organisms, or forms having weak free-swimming larvæ, for it is obvious that these could not contend against the seaward current of rivers and streams. The very exceptional occurrence of jelly-fish in fresh water is, for instance, probably due to

[1] *Op. cit.*, p. 235.

[2] *Ibid.*, p. 446. The figures given are 3·5 per cent. of dissolved salts, as an average for the existing ocean, and 0·85 per cent. for the primitive ocean in which we believe life to have originated.

the fact that they float at the mercy of every current; while among the groups which are poorly or never represented in fresh water we find a large proportion of forms which pass through a free-swimming larval stage. That this factor has been of great importance is confirmed when we examine those organisms which have effected a conquest of fresh water, for we find that in the majority of cases a free-swimming stage during development has been suppressed.

Of almost equal significance are the temperature differences between the waters of the ocean and of inland areas. It is quite evident that comparatively small masses of water, such as even the largest rivers and lakes, are more liable to variations of temperature than the vast waters of the ocean. In the tropics, a comparison between the ocean and a really large lake may show differences of little importance; but on the other hand, where the mass of water is small, as in ponds and streams, the contrast becomes very marked, and there is the additional danger that the water may entirely dry up. In temperate and colder climates there are often greater extremes, and in many cases equal danger to life, on account of the freezing of the water. The inhabitants of the more uniformly warm ocean, which is never subject to drying up or to freezing, will certainly find a difficulty in colonising where there are these undesirable features, and in fact it is only the forms which can fully adapt themselves to such altered circumstances that can make the change.

While these conditions have probably checked migration in a number of instances, there are types belonging to several groups which have become able to withstand high or low temperatures, as the case may be, or have devised means of surviving desiccation and freezing.

A few examples will serve to show the extremes which can be reached by forms which have been successful colonists. Certain Algæ and Bacteria have been found living in the water of geysers at temperatures up to 80° C., and a fish (*Haplochromis desfontainesi*) lives in Tunis in hot springs with a temperature of 75° C.

On the other hand, it is well known that most of our familiar plants are not killed by frost, though their vital activities are suspended, and a temperature of a little over 0° C. is sufficient for vigorous growth in the case of our earliest spring flowers and the plants of alpine and polar regions. There are animals, too, which can survive a temperature below freezing-point, but the cold in many cases induces a complete cessation of the ordinary functions of life. Frogs and toads, many fishes, and certain Mollusca can undoubtedly withstand such cold and resume their normal existence on the necessary increase in warmth. Further, it is a fact that the seas in the Arctic and Antarctic regions are often well stocked with life (largely Algæ and the lower Crustacea), in spite of a temperature little above, and sometimes definitely below, 0° C.

However, it is particularly in the case of fertilised ova that the power of resisting extreme cold is most marked, for in several groups specially protected winter eggs are produced, which appear able to survive almost any degree of cold. There are the gemmules of the Spongillidæ, and the hard-coated winter eggs of certain Turbellaria and Rotifers; also the resistant eggs of a number of Entomostraca (including the ephippial eggs of the Cladocera), and the so-called statoblasts of fresh-water Polyzoa. These are produced by the parent on the approach of cold weather, and in the spring give rise to new individuals, to replace the adults which have perished.

Some observations of Brauer confirm our belief that the winter eggs are produced with the definite object of resisting cold, and at the same time afford an interesting example of how inherited characters may continue to exert their influence under altered conditions. He found that the eggs of a certain species of *Branchipus* would not develop at all, until after they had been reduced to the temperature of melting ice.

Complete desiccation is a condition which is fatal to all organic life, so that those forms which are able to survive the drying up of a pond or stream have acquired some means of retaining a sufficient amount of moisture to make their continued existence possible. As this is obviously an unfavourable condition, it is not surprising that organisms lead during it a latent life which is strikingly comparable to that induced by extremes of cold. The African mud-fish (*Protopterus*) buries itself in the mud, and secretes an impervious cocoon in which it can exist for months, until the coming of the rainy season. Some adult Rotifers are capable of encysting themselves, and, in this state, of surviving long periods of drought, and the same is true of immature specimens of a species of *Cyclops*, and of certain Protozoa (*Amœba* and Infusoria).

It is nevertheless but a small assemblage of forms in which the adult is able to resist desiccation, compared with the much larger assemblage in which the power of resistance is confined to the reproductive bodies. This is precisely what we have seen to be the case as regards resistance to extreme cold; indeed, the two phenomena are closely akin, and it is not perhaps surprising that a protective coating to the fertilised ovum suitable for the one purpose should afford adequate protection in the other.

In the vegetable kingdom, many Fungi and Algæ produce highly resistant spores which serve for the perpetuation of the species, and the seeds of the higher aquatic plants can survive a dryness which would kill the parent stock. Among animals, resistant reproductive bodies, called by various names, are to be met with in several different groups, as we have already seen, and in certain cases where two distinct methods of reproduction exist, it is incipient drought alone which causes the production of these bodies before the adults succumb to the impossible conditions. In other cases, notably among the Cladocera, there are two fairly well-marked periods during which specially resistent ova are produced, the one during the summer, as a precaution against desiccation, and the other at the beginning of winter, to ensure protection from the frost.

In a manner perfectly analogous to what we have seen in the case of cold, it is found that the eggs of a species of *Apus* will not develop unless they have been dry for a considerable period.[1]

The most important reasons why fresh water has not proved easy to colonise have now been discussed, but there remain a few other points to be indicated, which may doubtless exert an influence at times. Organisms are directly affected by their interconnection with each other. That is to say, in certain cases they are dependent on one another to such a degree that the absence of one entirely precludes the presence of another which might otherwise be perfectly able to adapt itself to new conditions. This may be a matter of food-supply: a higher animal, for example, cannot extend its range into a medium in which its food, whether animal or vegetable, does not exist, so that if from any cause a river or lake were conspicuously deficient in this respect, it would stand little chance of receiving voluntary migrant forms from the ocean. There may be also a less obvious interdependence, concerning protection and shelter for a defenceless type.

Lastly, any impurity of the water of streams and lakes would act as an efficient barrier in many cases. The impurity might be merely mechanical, and due to large quantities of mud held in suspension, or chemical, and caused by the presence of salts or acids in solution. Examples of the former are well known, where during certain periods of the year rivers become well-nigh uninhabitable. Other rivers, and more particularly lakes, may carry in solution unusual quantities of lime or manganese salts, or may contain a considerable admixture of humic acid, and these conditions would be unfavourable to the majority of ocean types.

Before passing to other considerations, it may be well to again call attention to the fact that certain fresh-water organisms exhibit structural peculiarities which have undoubtedly been produced by existence under non-oceanic conditions. That is to say, actual morphological features have been created which in many instances enable them to be recognised as fresh-water forms. Some of these

[1] Semper, *op. cit.*, p. 175.

have been already indicated. The horny-coated resistant eggs, to which reference has been made, are structures characteristic of various fresh-water animals. The suppression of a free-swimming larval stage in certain cases may be accompanied by structural changes in the parent, having as their object the protection of the ova. Again, there is less need for stout protective armour in fresh water (particularly in ponds), so that fresh-water Gasteropods, for example, are usually distinguishable by their thin shells from their marine allies, which are fitted to withstand the breakers of the sea-shore.

In pointing out, however, the external characteristics which are directly due to the conditions under which these animals live, we would strongly emphasise the necessity for excluding such features as far as possible, when deciding the systematic position of any animal. It is only by doing so that we can gain a satisfactory idea of the true interrelationships of forms some of which have remained permanent inhabitants of the ocean, while others have secondarily become adapted to life in fresh water.

Having examined in some detail a number of facts which bear directly on the colonisation of fresh water from the sea, we must now proceed to consider the means by which this process actually took place. It is obvious that fresh-water organisms must have attained their present distribution in one of three ways: (1) by a direct, active or passive, migration from the sea; (2) by becoming terrestrial or swamp-loving in nature, and secondarily adapting themselves to life in fresh water; (3) as a result of the isolation and subsequent freshening of some portion of the sea, due to movements of the earth's crust.[1] No doubt fresh-water organisms have been derived from marine by all three of these methods, but it is by no means easy to assert which of them has played the most important part. In passing to the consideration of the methods in more detail, we must seek to determine whether the known fresh-water forms possess characteristics which would fit in with the suggested explanations, and we may also indicate the particular manner in which the more important groups achieved this material change in their environment.

Treating in the first instance the subject of active migration,[2] it is clear that this means is only open to strongly-swimming forms or to such as walk or crawl on the bottom, for these alone would be able to invade rivers from their mouths, and so effect a permanent settlement within them or within any associated basin of water. We think at

[1] *Cf.* Sollas, "The Origin of Fresh-water Fauna," in *The Age of the Earth, and other Geological Studies*, London, 1905, p. 178.

[2] We are dealing for the moment only with the emerging of marine types to become members of a purely fresh-water series. Migration from one area of fresh water to another is a separate question.

once of the fishes, most of which are probably capable of directly colonising our rivers and streams, and some of which (salmon, eel, sturgeon, lamprey) are still in the habit of migrating from salt water to fresh. Then there are certain Crustaceans which may very well have actively invaded fresh water. These are the crabs, prawns, and crayfishes, which by swimming or crawling would be capable of making headway against the current of a river.

An examination into detail shows us that these forms have acquired characteristics which have fitted them for colonising fresh water in the way suggested. Most fresh-water crabs, unlike their marine allies, which are liberated from the egg as free-swimming larvæ (Zoea), remain in the shelter of the female's abdomen until they have reached their adult form, while the young of the crayfish remain attached to the swimmerets of the female until able to lead an independent existence. In the case of fresh-water prawns, we appear to have merely an increase in the amount of food-yolk, which at least ensures that the larvæ are set free at a more advanced stage than the corresponding marine types. This is actually to be seen within the limits of a single species, in the case of the prawn *Palæmonætes vulgaris*, which is known to inhabit both the sea and fresh water. The eggs of the individuals living in the latter are larger, and hatch out at a later stage, than the eggs of marine specimens. All the modifications just pointed out have, of course, the one object—that of enabling the young to retain the hold upon fresh water which their parents have acquired, by the more or less complete suppression of a free-swimming larval form, which would be at the mercy of every current.

We may perhaps be justified in including the genera *Asellus* and *Gammarus* among the types which have actively migrated from the sea; in both cases the eggs are retained within the brood-pouch until the adult form is approximately reached. The leeches too we can consider as forms which may have actively colonised fresh water, for they are powerful swimmers, can attach themselves firmly to rocks or stones, and either deposit the eggs in a horny cocoon or carry them upon the ventral surface of the parent.

That a number of the Mollusca which we find in fresh water migrated directly from the ocean there can be little doubt. Both Lamellibranchs and Gasteropods could actively accomplish this, for, though slowly creeping forms, they would in time reach great distances from the mouth of a river or stream. Here again we have striking examples of how—to avoid the danger of being swept out to sea—the free-swimming larval forms characteristic of their marine relations have become suppressed. In the well-known genus *Bythinia*, for example, eggs well provided with food-yolk are attached to stones and water-plants, and the young emerge in practically the adult condition. In *Paludina*, a stage further has been reached, for the ova are retained within the body of the parent, and the young are born alive. This is similarly the case in the fresh-water bivalves *Cyclas* and *Pisidium*, which are provided with brood-pouches in which the eggs develop.

Turning to consider passive migration from the sea, we realise that, if this has taken place, it must have been mainly by the transport of sessile or feebly-swimming forms, through the agency of those which are actively locomotive. We have already seen how tidal influence may carry certain marine organisms for some miles inland, but this process could not effect the colonising of more than an estuary, and that only under exceptional circumstances. While it is likely that a considerable number of small organisms, both animal and vegetable, are passively carried from the shores of the ocean into rivers and lakes, it is improbable that many survive the sudden change in environment. It is conceivable, for instance, that ova or encysted animals might be left dry upon the beach, and transported by winds to fresh-water surroundings, but there is not much likelihood that they would successfully accommodate themselves to the altered conditions. Again, quite a number of diverse organisms might be carried from the sea-shore to fresh water sticking to the feet of wading birds, and some forms might adhere to active immigrants such as fishes and perhaps Crustaceans.

A case which seems fully proved, in which animals have been conveyed by fish directly from the sea to fresh water, is that of the parasitic fish-louse *Argulus*. Species inhabiting both fresh and salt water have long been known to occur, but it was reserved for Wilson [1] to prove by experiment that, in certain instances at any rate, the change of medium produced little effect, even if suddenly made. Other parasitic forms which are probably direct but passive immigrants from the sea are *Lernæocera*, *Achtheres*, and a Bopyrid.[2]

A truly remarkable example of sessile forms which take advantage of the locomotory power of fishes may find fitting mention here. We refer to the interesting reproductive habits of the fresh-water mussels *Anodon* and *Unio*. The ova undergo partial development within the parent, but, arriving at the larval stage known as the glochidium, are expelled into the water, provided with a long adhesive filament. If the latter comes into contact with a passing fish, the little larva becomes attached, and by means of the sharp spines on its shell secures its hold. The epithelial layers of the fish soon grow to enclose the embryo in a definite cyst, and within this

[1] *Proc. U.S. Mus.*, vol. xxv., 1903, p. 648.
[2] Semper, *op. cit.*, p. 147.

the further development takes place, aided probably by nutriment obtained from the host by means of outgrowths penetrating the tissues. When the young mussel is fully formed, the cyst bursts, and the mussel falls to the bottom to assume a sedentary life. Whether this wonderful method afforded the means by which the mussels were enabled to colonise fresh water is doubtful. It is more probable that the process has been entirely evolved since they assumed a fresh-water habitat, and that its object has been to assure adequate distribution within the limits of that medium.

We have now to deal with the second method by which organisms primarily marine have come to inhabit fresh water, namely, by becoming terrestrial or swamp-loving in nature, and secondarily adapting themselves to a fresh-water life. In the first place, we are fully justified in supposing that the forms belonging to groups overwhelmingly terrestrial in character come into this category, and are modified land forms and not direct immigrants. This is in all probability the case with the majority of the higher plants; indeed, amongst the Angiosperms there are species living in swampy surroundings which can perfectly withstand changes from an almost wholly terrestrial to a partially submerged existence.

It is equally obvious that the Mammalia are an essentially terrestrial group, and that therefore fresh-water mammals (as, of course, marine mammals) have become secondarily adapted to a very different mode of life. The same is presumably true of the insects and arachnids which are now constituents of the fresh-water fauna. Finally, we may mention certain fresh-water Gasteropods, which belong to the great group of air-breathing forms (the Pulmonata) and so may be supposed to have secondarily arrived in our rivers, lakes, and swamps. Among the most common genera belonging to this group are *Limnæa*, *Planorbis*, and *Ancylus*.

The third method by which fresh-water organisms have been produced—by the isolation and freshening of portions of the sea—is a wholesale method, which must have acted upon a number of most diverse forms. It is, of course, clear that in a basin isolated by earth-movements from the sea there would probably be many organisms totally unable to accustom themselves to a fundamental change in salinity, however gradually that change might be accomplished.

There are certain indications afforded us as to which forms could survive, both by the experiments of Beudant and by the instances of partial direct colonisation by marine types which have already been discussed. We have also seen sufficient evidence that this process has actually been at work, but it is nevertheless practically impossible to point out the groups which have become inhabitants of fresh water in this manner. The temptation is to assume that all the organisms in our fresh-water flora and fauna not easily accounted for by one of the other methods are the modified descendants of those left in detached marine basins, but there is no justification for such an extreme view. Speaking broadly, we may say that those forms which are too feeble to migrate actively from the sea, and are unprovided with any means for securing their transport passively, are those which we should account for by this third method. It is very evident, however, that these questions involving the relations of organisms to their surroundings are of extreme complexity, and demand a degree of knowledge far beyond the small beginnings hitherto made. In many instances we may be suggesting theories which are quite far-fetched, and subsequent discovery may show much simpler explanations.

We turned our attention in the first instance to the very striking differences which exist between marine and fresh-water organisms, no matter in what quarter of the globe we compare them. If we turn now to a comparison between the fresh-water organisms of different parts of the world, we find an equally striking similarity between them. This uniformity of fresh-water organisms, sufficiently marked when we knew little outside the bounds of Europe, has become more and more strongly emphasised as information has been collected from the remoter regions of the world. It is not asserted that forms from widely separated fresh-water areas are necessarily identical, but we frequently find generic, and sometimes specific, resemblances, while there is a general uniformity far more pronounced than any to be observed in marine organisms. There are, of course, differences of a minor nature due to differences of climate, and these we must treat of in detail elsewhere; but we are concerned for the moment only with the very natural query: Why does this very definite uniformity exist?

Some of the facts which appear to offer a clue have already been indicated. We have examined at some length the dangers and difficulties to which forms colonising fresh water are exposed, and have pointed out the means adopted by different groups for overcoming them. Knowing this, we can explain why certain types only are to be found in all the fresh waters of the globe—they alone have been able to adapt themselves to the peculiar conditions. But when we leave on one side the actual origin of fresh-water life, and study the agencies which have secured the distribution of these forms from one centre to another, we gain more light on our problem at once.

It will be remembered that, under the heading of active and passive migration from the ocean, several methods were referred to which would be equally capable of effecting a general distribution within the limits of fresh water. It was no part of our proposition that the process of colonisation took place everywhere simultaneously, and to an exactly corresponding extent; indeed, that would not entirely explain the phenomenon, for we know that artificial reservoirs and ponds become in time stocked with characteristic forms. But at the present day, as in the past, plants and animals which have accustomed themselves to life in fresh water, wherever that may have taken place, tend to become widely distributed from their centre of origin.

The agencies which have effected this distribution are to a large extent those we have already discussed in the other connection, but we shall see that their relative importance is not necessarily the same, and that there are certain others to be mentioned. Active swimming or crawling animals, such as fish, certain Crustacea, and molluscs, would be able to make their way from one river-system to another, probably at a wet season of the year. We may add to the list of actively migratory forms several aquatic insects (such as *Dytiscus* and *Nepa*) which are known to be powerful flyers, capable of making long excursions by night.

But passive transportation has probably been the most effectual agent in securing the spread of fresh-water organisms. This may be by the aid of active forms, such as birds or insects, or by purely mechanical means, but it is in either case directly associated with the power of resisting unfavourable surroundings, which we know has been so notably acquired in many instances. Darwin himself studied this matter many years ago, and gives some suggestive facts in his great work, *The Origin of Species.*

There seems little doubt that the enormous range so characteristic of many fresh-water and swamp plants is largely due to the seeds being carried long distances in mud adhering to the feet and beaks of wading birds. This is doubtless also the means of transport for the resistant reproductive bodies of various fresh-water animals. An experiment which Darwin carried out certainly suggests that a number of molluscs may be distributed in a similar way, attached as small newly-hatched individuals to the feet of aquatic birds.

Turning from birds to insects, we have evidence that sometimes, at all events, strongly-flying forms have carried with them in their flight small bivalves firmly adhering to a leg. We have seen how the locomotory power of fishes has been made use of by the mussels *Anodon* and *Unio*, but fishes may be instrumental too in effecting the distribution of certain plants. Fresh-water fish often swallow various seeds, which may retain their power of germination when passed after some time in the fæces.

A further example of passive migration is interesting as being due to artificial assistance. This is the case of *Dreissensia polymorpha*, a small mussel which appears to have spread enormously within recent years in our European river-systems. By the byssus, which is characteristic of these forms, it has attached itself to ships and rafts, and so procured transport from place to place. It should be noted that *Dreissensia* still retains a free-swimming larva, which thus secures the distribution of the species through all parts of a river below that to which the adult has been carried.

We have already referred to dispersal by the agency of wind. There is no doubt that this is most important in the case of small invertebrates which are able to encyst themselves, and in the case of those forms producing ova which can resist desiccation. Certain Rotifers, a species of *Cyclops*, and some Protozoa come into the former category, but into the latter comes a much greater number of types. We include the gemmules and statoblasts of sponges and Polyzoa, the summer eggs of various Entomostraca, and the horny-cased eggs of *Hydra* and the Rotifers. No doubt we may add to the list the seeds and spores of diverse aquatic plants.

The matter is peculiarly interesting in the case of Rotifers, which often appear in sporadic fashion in widely separated areas thousands of miles apart. We are as sure as we can be of anything in this somewhat speculative domain, that this remarkable discontinuous distribution is due to the transport of the ova (in some cases perhaps the encysted adults) by means of wind. The eggs are very minute bodies, few of them exceeding a three-hundredth of an inch in length, and many considerably smaller, so that they are specially adapted for transport with dust by the aerial currents which circle the globe. The finding of isolated specimens in remote districts, more striking amongst the Rotifers than in the case of most other animals, is a direct index of the minuteness of their resistant ova, which affords special facilities for wind-transport.

One other means may be mentioned as occasionally effecting the dispersal of fresh-water organisms, and that is the agency of floods. In flood-time barriers of river-systems may break down; but without going as far as this, we may conceive of local varieties, or even species, being swept from their point of origin in some backwater, and widely distributed within the same river-basin. Isolated ponds and lakes may receive in times of flood many organisms from a distance, or on the other hand they may have peculiar and characteristic forms carried out of them by the overflowing waters.

Enough has now been said to make it clear that the organisms which actually constitute the present-day fresh-water flora and fauna are unceasingly subject to dispersal within the limits of that medium, by a variety of different means. This being so, what is more likely than that these organisms should assume and retain a uniformity which, while not precluding differences of a minor degree, is far in excess of that observable in the ocean, where the conditions of life are so profoundly distinct?

While the incessant dispersal of forms tends to hinder the creation of new varieties and species, it must tend to produce types which are hardy and adaptable, and therefore thoroughly fitted to survive. In this connection a suggestion has been put forward which goes a little further than we have ventured, but without denying the essential truth of our assertion. It is that the uniformity of fresh-water organisms is due to the persistence of the hardy adaptable types of cosmopolitan distribution, and the dying-off of local types, as a result of altered conditions. The local varieties, which under more favourable circumstances might have attained specific rank, are regarded as having frequently succumbed to the combined effects of changing conditions and the relentless competition of more adaptable generalised forms. It may be so; but, although our present knowledge of this intricate problem is very far from complete, there is no need to look beyond the exceptional capacity for dispersal for an explanation of this phenomenon.

This, then, is the conclusion we arrive at respecting the general uniformity of the organisms of fresh water. We are able also to assert confidently that fresh-water organisms are the modified descendants of marine ancestors, and we have indicated at considerable length the different ways in which we conceive the colonisation of inland waters to have taken place. On the earlier question we set ourselves—that of the existence of only certain forms in fresh water—it is more difficult to reach a conclusion. Many causes have been enumerated, each of which may have had its effect in preventing this or that type from leaving the littoral zone for the inland waters of a continent, but we are still confronted with exceptions which we cannot explain, both of forms which have unexpectedly succeeded in migrating, and of others which have incomprehensibly failed to do so. We are, in fact, face to face with some of the most profound of Nature's problems, and while we may safely predict that increasing knowledge will throw light upon many obscure matters, the time is far hence when we shall be able to unravel the complex effects produced on living matter by the influence of animate and inanimate surroundings.

SUMMARY OF OUR KNOWLEDGE REGARDING VARIOUS LIMNOLOGICAL PROBLEMS

By Dr C. WESENBERG-LUND

CONTENTS

INTRODUCTION

On a visit to Copenhagen in July 1909 Sir John Murray asked me to give him my views on matters connected with fresh-water lakes, their variations with latitude, and other physical and chemical conditions, as also regarding the variation of the organic life, especially the plankton, from pole to pole.

It must be remembered that a detailed review of the variations in the outer conditions (*i.e.* variations in the physical and chemical conditions of the lakes) from the pole to the equator would be the same as an account of the general geography of the lakes; this can hardly be done satisfactorily at present, at any rate not by the author, as he does not have sufficient mastery over all the elementary arguments on which an account of our present knowledge is necessarily dependent. Further, it must be remembered that our knowledge of the physical and chemical conditions of the lakes of the tropics is extremely slight. What I have tried to do in the following, with regard to the Arctic, North European, Central European lakes of the level country (Baltic lakes) and the alpine lakes, has been to bring together the available information concerning the topography and general geography of the lakes: morphometry, bathymetry, littoral region with littoral vegetation, character of the soil in the drainage area, precipitation, temperature, chemistry, colour, and transparency of the lake-water. In Part II. I have tried to give a sketch of the plankton communities, their geography and life-history; and in Part III., according to Sir John Murray's special wishes, to expose my views with regard to the main problems of future limnological investigation.

PART I.—CONTRIBUTION TO THE GENERAL GEOGRAPHY OF THE LAKES

The Arctic Lakes

If we try to form a picture of the arctic lakes, we have unfortunately but few certain facts to rely upon. It is only by means of general descriptions of the nature of the arctic regions that a vague and uncertain sketch, which must be corrected and added to in future, can be given. During the last ten years I have read many accounts of travels in the arctic regions, hoping to find accounts of arctic lakes. From this literature I shall attempt to give an outline of the nature of arctic lakes and the conditions of life which they offer their organisms.

The rainfall is stored as large snow and ice-masses, of which but a small part, and that only for a short period of the year, breaks forth from the ice into the lake-basins in the form of torrential rivers. The *country surrounding* the lakes is perpetual snow, naked rock or sparingly coated (moss-covered) rocky slopes, sometimes wide tundras frozen throughout the whole or at any rate the greater part of the year.

No account of the *sizes* and *depths* of arctic lakes on which to found a general description is available. The descriptions of travellers convey the general impression that the arctic lakes are comparatively small. In the real lakes the littoral zone is always narrow, the pelagic region reaching up to the shore. The primary lake bottom is rock or rough sand and gravel. The height of the water will undergo considerable variations: high water in spring, low water in autumn. In lakes near the margin of the ice, where the affluents are rivers of cold water from the inland ice, the water is surcharged with particles of clay. The filling up of the real lake-basins probably proceeds very slowly; the material deposited is mainly sand and clay with a slight admixture of organic material. Porsild (1902, p. 207 [1]) remarks that the bottom material was never finely pulverised mud, but generally large, well-preserved particles. The deposited *bottom* material was odourless, and thus probably destitute of bacteria, all processes of decomposition going on very slowly.

The *transparency* and *colour* of the water vary a good deal: in the clay-filled lakes the water is grey and the transparency very slight; in lakes not directly fed by rivers from the inland ice the water may be exceedingly clear and the transparency great (Vanhöffen, 1897, p. 169). With regard to the *chemical* composition of the lake-water we do not know anything, but we may advance as an hypothesis that whilst farther south the chemical nature of the lake-water, the quantity and quality of decomposed and suspended organic and inorganic constituents, are dependent upon the heterogeneous nature of the surrounding country of the lake territory and vary from lake to lake, this is hardly so much the case in the arctic zone, where the differences in the nature of the surrounding country are not so great; further, we may suppose that the lake-water will prove to be exceedingly poor in lime everywhere in the arctic regions.

Our knowledge of the *temperature* of the lakes is also very incomplete. We know only that the arctic lakes are open but few months of the year. Many of the lakes examined by Ekman (1904, p. 10) in Sarek were never quite free from ice. Three small lakes were covered with ice of a thickness of 2 m. even on the 27th July 1903, and are supposed to thaw only in very warm summers. The lakes examined by Greely on Grinnell Land at 82° N. lat. were free from ice only during one and a half months, from the middle of July to September. A great many high arctic lakes are thus no doubt of Forel's type of polar lakes, the surface temperature of which never exceeds 4° C. and the bottom temperature of which is $\overline{\overline{<}}$ 4° C. They have always "inverse stratification," the water resting in layers almost throughout the year, the colder above the warmer; in summer they have a very short period of circulation (Forel, vol. ii. p. 303). So far as I know, the temperature of such lakes is only known from theoretical considerations. The only lake of whose temperature we have some knowledge, and, as far as I know, most like Forel's type of polar lakes, is the large deep Torne Träsk in Swedish Lapland. According to Ekman (1904, p. 8), it was still almost homothermous on the 25th July 1900, four weeks after it had thawed, with a temperature of 3·1° C. at the surface and 3·3° C. from 70 to 85 m. Even in July the lake had thus not yet attained the temperature of

[1] The full reference to the literature cited will be found in the bibliography at the end of the paper.

4° C. and the stratification was still "inverse." In the middle of July 1903, however, the lake had a temperature of +9° C. at the surface, from which it appears that even this lake cannot, at any rate not every year, be classed among the polar lakes. From another lake, high northern even if not arctic, the lake of Enare, sometimes frozen ten months of the year (?), we have fairly detailed data of temperature (Pettersson, 1902, p. 13); but these, in my opinion, seem so improbable (on the 6th August, 10° C. at a depth of 80 m.) that they can hardly be considered as quite reliable. In many of the shallower lakes, even those situated under well-marked arctic conditions, the temperature indeed rises to 10–14° C., on warm sunny days in summer even to 15° C. (Vanhöffen, 1897, p. 173; Ad. Jensen in Wesenberg-Lund, 1907, p. 67; Ekman, 17·5°, 1904, p. 12), but according to the last-mentioned the temperature rapidly sinks again. In such lakes, consequently, there are two or probably many periods of circulation, but these occur very shortly after each other, and are limited by a long winter period of stagnation.

In order to judge of the conditions which the arctic lakes may offer to the organisms and especially the plankton, it must further be remembered that, taken on the whole, the arctic lakes are extremely dark, as their waters throughout the greater part of the year rest in complete darkness below several metres of snow-covered ice. As a sort of compensation, the lakes which thaw during the short arctic summer, when the days and nights differ but slightly, will be greatly lighted up for a short period owing to the great purity of the water.

We do not know anything of the extreme limits for the vegetation in the arctic lakes. As a matter of fact, the Characeæ are fairly common in arctic lakes, but we are not aware whether they form here a special Characea zone. On the other hand, from Kruse's (1898, p. 386) and Porsild's (1902, p. 200) descriptions we know that *Hypna* at all events goes down to about 3 m. or even more. Nearer to the shore a zone of *Potamogeton* may be found (Porsild, 1902, p. 206); but, all in all, the belt of vegetation in the real lakes of the arctic zone is very narrow. Of great interest is the observation of Porsild (1902, p. 204) that the surface of the precipitous cliffs is covered with a coarse felt of stalked Diatom colonies. That the vegetation in more southern small lakes, ponds, and pools is extremely rich is a well-known fact; many valuable descriptions of this vegetation and its life-conditions have been recorded in Warming's (1888, p. 127) paper, and further by Rosenvinge (1898, p. 239), Hartz (1898, p. 42). Kruse has drawn an interesting picture of the transformation of lakes into pools or tundras (1898, p. 384).

The arctic lakes, in contrast to the southern lakes, are characterised by their great monotony; uniform conditions are offered by the fresh water to its organisms everywhere in the arctic zone from lake to lake as well as in all localities within the same lake.

The North European Lakes

The uniform character of the arctic lakes does not characterise the lakes of the northern temperate zone. The country surrounding the lakes is most varied: perpetual snow, naked rock, but much oftener beds of moss and peat which creep round the mountain crests and clefts like a mantle, in Scotland about ¾ m. thick, and through which the water oozes on its way down to the water-basins; wide bogs, forests with humic acid ground, and in part, but to rather a slight extent, arable land.

The *height* of the surface of the lakes above the level of the sea is extremely variable. The zone contains numerous mountain lakes, especially in Norway and North Sweden, elevated into completely arctic conditions, and many, *e.g.* several Scottish lakes, very near the level of the sea. The *shape* of the lake-basins is often long and narrow; a great many may no doubt be considered as exceedingly large pre-glacial river-beds, formed by erosion (see Ahlenius, 1900, p. 28; 1905, p. 17); their *depth* is often very considerable. More than half of the twenty-seven European lakes whose depth exceeds 200 m. lie in Norway and Scotland, and the four deepest lakes of Europe are in Norway (Hornindalvatn, 486 m.) and Scotland (Loch Morar, 329 m.) (see Holmsen, 1898–9, p. 1; Helland, 1872, p. 538; John Murray, 1904c, p. 67, and Halbfass, 1903–4, p. 221). Most of the lakes are of medium size or small; still, the zone includes several large lakes—the great Swedish and Finnish-Russian lakes. A great many, especially the Scottish and many Norwegian lakes, have exceedingly precipitous *sides* with depths of more than 100 m. near land. The shores are generally covered with rubble-stones, dislodged and rounded by the waves; in front of the river mouths we often find large, well-marked delta formations, in sharp contrast to the firm rocks. Still, a littoral region is probably in many cases, especially in the deeper lakes, fairly sharply delimited from a pelagic region, differing from the latter by greater variations in temperature. Only in very few cases is the *bottom* naked rock; the primary lake bottom is probably always covered by secondary deposits. In Scottish lakes it can be stated that lime is absent except where the rocks are limestone, and most probably also in the great majority of Scandinavian lakes, especially those north of the large Swedish lakes. In so far as the surroundings mainly consist of snow and the ground is frozen in winter, the *height of the water* will undergo regular periodical variations, being highest in early summer and decreasing later; where the surrounding country is moss-covered mountain slopes, always saturated with water, and rarely frozen, every period of heavy rains will at all times of the year send immense masses of water down into the lake-basins. In both cases the height of the water undergoes very considerable variations, but these are in the former case periodical, in the latter quite irregular (Scotland).

The *chemical* composition of the water is much less uniform than in the arctic regions. On the whole, it must be considered poor in lime; during its passage through layers of moss and peat a considerable portion has absorbed large quantities of humic acids; the lakes are further filled with organic material to a much higher degree than the arctic lakes, and this in suspended form is carried out into the lakes from the surrounding territory. Owing to the steep course of the affluents, this material is very rough; and, owing to the steep rocky sides of the lakes, much of this rough material (branches, leaves, hay, fruits) in unpulverised form is carried out even into very great depths (100 m. and over). Here the material, owing to the preserving action of humic acids, does not decay, but undergoes only a slow process of disintegration, the result of which is a remarkable sort of liquid brown peat (G. West, 1905, p. 968). Lakes with clay-filled water such as often occur in arctic regions are no doubt rare. The *transparency* of those lakes in which the water is coloured by humic acids (especially the Scottish) is very slight, generally only 5–7 m., and the *colour* of the water is brown (Bachmann, 1907, p. 7). Some of the Norwegian lakes are remarkable for their exceedingly great transparency, 14–18 m. (Huitfeldt-Kaas, 1906, p. 130); brown lakes are rare. Huitfeldt-Kaas mentions that the transparency of the water in Norway is much more influenced by detritus than by plankton (p. 126). The lakes are for the rest subject to the same fate as the surrounding territory; their surface receives only little direct *sunlight*; the rainfall is everywhere great; through long periods of the year, especially in Scotland, immense clouds and fogs shroud the country and persist longest in the valleys where the lake-basins occur. The low summer temperature with the usually very humid atmosphere do not allow of any appreciable evaporation from the surface, and consequently no great *concentration* of the water takes place in summer.

This zone presents greater variations in *temperature* than perhaps any other. It contains some lakes which, like several of the large Scottish lakes, must be classed among the tropical lakes, with water at a temperature $>4°$ C. throughout the year, *e.g.* Loch Katrine, the temperature of which hardly sinks below 4°·44 (Pettersson, 1902, p. 8; Forel, 1901b, p. 35), and Loch Ness, the surface temperature of which rarely sinks below 5° C., and which at any rate never freezes;

and quite polar lakes, which as a rule are covered with ice throughout the year. Between these two extreme limits all conceivable transitions occur.

It may further be mentioned that the annual range of temperature variation for all the lakes of the zone is slight, and for many probably slighter than in any other zone. In the Scottish mountain lakes at the surface the yearly temperature variation is only about 5–13° C. (Loch Ness, 41°·5–56°·3 Fahr., Wedderburn, 1907a, p. 412); for certain Norwegian high mountain lakes only about 0–2° (Holmsen, 1902); Thingvallavatn 1–11°, Myvatn 0–12½° (Wesenberg-Lund, 1906, pp. 1105 and 1140); Mjösen 0–12° (Pettersson, 1902, p. 14); Huitfeldt-Kaas, 1905, reports 17°·3, but this temperature hardly occurs every year; Ladoga 0–9°·9; Wettern 0–13°·32 (Pettersson, 1902). The ice phenomena of Norway have been specially studied by Holmsen in his fundamental work (1902), by Ahlenius (1900, p. 28); see further Holmsen (1902, pp. 1–15); owing to the more special character of this exceedingly interesting literature it is merely mentioned here.

This comparatively low summer temperature is common to all the lakes of this zone; only exceptionally it may probably exceed 12–14° C. The bottom temperature of many of the deep lakes does not sink below 4° C. In the temperate lakes of the northern European zone we find two periods of circulation (spring and autumn), separating a long winter period of stagnation from a short summer period of stagnation; during the greater part of the year "*inverse stratification*" prevails. In these lakes we meet with the so-called "Sprungschicht," which only exceptionally occurs in the lakes of the arctic zone, and at any rate has hitherto hardly been discerned there. Ahlenius found it in Saggat lake, about 68° N. lat. (1900, p. 35). In many cases, at any rate, we may account for the formation of a "Sprungschicht" in the following way:—The variations in the temperature of the air, day and night, are now so great throughout such long periods of the summer half-year that uniform heating of the surface water is no longer possible. Owing to the cooling of the surface at night and during periods of cold weather, vertical currents which equalise the temperature arise; in different seasons they reach different depths. Above these depths a somewhat uniform temperature is consequently met with; below them the temperature slowly decreases towards the bottom. The decrease in heat proceeds more slowly the deeper the water, most quickly at the upper limit, *i.e.* nearest the lower limit of the upper uniform, warm layer. Here the variations in temperature may be so great that they proceed by jumps, and therefore this layer, according to the usage introduced by Richter, is generally called "Sprungschicht" (thermocline by the Americans).

In temperate lakes it will generally appear in June, and sink deeper and deeper in the course of summer until it reaches its deepest point in autumn and then disappears during the cooling processes.

It appears from the researches in Mjösen, Wetter, and Ladoga that the "Sprungschicht" is at its deepest point, at about 20–30 m., in the beginning of September; the change in temperature may here amount to 3–5° C. Quite different phenomena have been observed by Wedderburn (1907a, p. 407; 1907b, p. 1) in Loch Ness.

I am inclined to believe that a great many northern temperate lakes, especially those of the tropical type, are most probably characterised by the deep-lying position of the "Sprungschicht," or, in other words, by the great thickness of the layer of water where the temperature is uniform. The reason is perhaps partly the small quantities of plankton in these northern temperate lakes, partly the effect of wind upon water-basins of an almost always very elongated form, though principally the mild winters in the western parts of the zone.

It is clear that the *currents* in these lakes are much stronger than in the polar lakes, a fact which is of very great importance for the migration of the plankton. The seiches have been studied by Holmsen (1898, p. 1) in Norwegian lakes, but especially by Chrystal (1905a, p. 599; 1905b, p. 637) and Chrystal and Wedderburn (1905, p. 823) in Scottish lakes.

Of the *vegetation* in the lakes and its arrangement in zones we know exceedingly little. The vegetation in the Scottish lakes was studied by G. West (1905, p. 967), that of the Faroes by Ostenfeld (1906, p. 62). From Iceland, Norway, and the northern parts of Sweden and Finland we have very little information. The vegetation in the lakes seems always to be very slight; we do not know to what depth the wholly submerged vegetation belts of *Characeæ* and *Fontinalis* penetrate; in the Scottish lakes it is commonly not great, according to West, on account of the dark, peaty water. A remarkable difference between the lakes in this and the following zone is that the *Potamogeton* belt is not very distinct; the belt of *Phragmites* and *Scirpus* so characteristic of the Baltic lakes is either weakly developed or quite absent. The low temperature, the shores as a rule steep and covered with rolling stones, the wave erosion, the slight detritus formation, the fact that the water is usually slightly transparent and the percentage of lime generally small, are all instrumental in causing the vegetation belts of the North European lakes to be weakly developed.

In localities where the transparency is greater, the percentage of lime in the water great, and where the shores are evenly sloping, we find lakes where the vegetation belts are as broad as those of the

Baltic lakes (G. West, 1905, p. 968). Here the *Characeæ* go down to 20–25 feet, and *Fontinalis antipyretica* even to 40 feet (G. West, 1905, pp. 982–983).

The conditions offered to organisms by the real lakes and by the small ponds and pools differ greatly; in the latter especially, the variations in temperature are very great, principally in spring. There is therefore a very considerable difference between the fauna and flora of the pools and of the large lakes, especially in the southern parts of the zone. There is, however, but little information on these matters as yet.

The Baltic Fresh-water Lakes

A great many researches enable us to judge of the conditions of life in the Baltic lakes; the most important will be mentioned in the sequel.

Many countries bordering upon the Baltic are very rich in lakes, especially Finland, Pomerania, and Prussia, to a somewhat less degree South Sweden, and Denmark least of all. The great majority of all these lakes are in some way indebted to the Glacial Age for their origin. Their number was formerly much greater, and the area of the present lakes also much larger. From a series of valuable papers we can judge of the origin of the North German lakes, their topography and geography (see especially Geinitz, 1886, p. 1; Wahnschaffe, 1891, p. 1; Bludau, 1894, p. 1; Steusloff, 1907, p. 427; Halbfass, 1901, p. 1, 1903a, pp. 592 and 706; Braun, 1903, p. 1, 1907, p. 8; Seligo, 1900, p. 1, 1905a, p. 1, 1907, p. 1; Ule, 1894, p. 1, 1898, p. 25; Penck, 1894, vol. ii. p. 266; Keilhack, 1887, p. 161).

From Sweden we have principally Trybom's investigations of the lakes in Jönköping and Malmöhuslän (1893, 1895, 1896, 1899, 1901). The Swedish explorations give us information regarding the glacial lakes of former times and the kind of soil left by them. It has been shown how lakes have been dammed up by the masses of ice of the Glacial Age, and how, on the retreat of the ice, the water has hollowed out enormous valleys by erosion and left a drained lake-bottom consisting of clay and sand. In the case of several lakes it appears that the ice has kept the height of the water far above that of the present time, so that a number of the present small separate lakes were formerly only one large lake. On all this see especially Gavelin (1907, p. 1), Munthe (1907, p. 1), Westergård (1906, p. 408), Bobeck (1906, p. 481).

For Danish lakes we have no corresponding literature; here only Madsen (1903, p. 1) can be cited.

It is common to the lakes recorded here that they hardly deserve this name. All come under Forel's definition of pond-lakes, and innumerable transitional stages occur everywhere between such as exhibit as much of the lake character as it is possible to find in the region dealt with and the smallest ponds and drying-up pools. One of the features to a great extent characterising the landscape of the Baltic district is just its great number of small lakes, ponds, and pools.

Characteristic of all the lakes of this zone is their uniform appearance. First and foremost, nearly all are lakes of the level country; their *height* above the sea varies little and is very rarely over 200 m. Only in Riesengebirge, Eifel, and Schwartzwald do some more elevated lakes occur. The *country surrounding* the lakes exhibits everywhere a similar appearance: never perpetual snow, rarely naked rock, but fertile forests, meadows, and arable land, in part bogs and heaths. The ground is nearly everywhere loose and easily worked, and consists mainly of humus, clay, and sand, often mixed with considerable quantities of lime. The lakes are generally of small size, rarely over 3000 hectares, and all shallow; the *depth* rarely exceeds 30–40 m., and attains at most about 70 m. The *shape* of the lake-basins is often circular; steeply sloping sides are rare, and there is generally a very broad littoral region, on the windward side covered by sand or gravel, on the lee side by detritus, peat formations, etc. (Klinge, 1890, p. 264). The *bottom* mostly consists of soft lake-bottom deposits, the so-called lake "gytjes," very rich in organic material and very often highly charged with lime; the quantity of lime is often so great that the bottom layer may be directly used as marl to improve the arable soil.

Great variations in the *height of the water* do not generally occur. Neither sudden thaws nor violent torrents will produce appreciable variations in the height of the water, as the loose ground everywhere absorbs the moisture and the slope is so slight. Owing to the low banks, even a slight sinking of the surface of the water is very visible, and involves a very great restriction in the area of the lake in autumn. The decrease in the height of the water naturally results in an increasing *concentration.* This becomes much more evident as, on account of the slight declivity of the land, the water is on the whole slowly renewed, and especially so in summer.

With regard to *temperature* also the lakes of this zone present great similarities. Polar lakes do not occur, tropical lakes hardly ever—they are at any rate rare. The great majority are frozen during a shorter or longer period of the year, yet only exceptionally for more than three months. It happens in certain years that the lakes, on the whole, do not freeze at all. A very high summer temperature is common to all the lakes; it probably always exceeds 18° C., not rarely it is 24–26°, and may even be higher. Owing to the slight depth of the lakes, the summer temperature at the bottom is probably everywhere >4° C. The surface temperature varies in the course of the year at any rate from 0° to 24–26° C. The high summer temperature is to a great extent due to the broad littoral zone, the water of which in early summer is heated above the temperature of the air in direct sunlight. The heat collected is distributed by currents through the whole water of the lake. Owing to the shallowness and small size of the lakes, they follow the variations in the temperature of the air on the whole fairly exactly. The summer period of stagnation is probably longer than the winter period throughout the greater part of the zone. In all the deeper lakes there is a very distinct main "Sprungschicht," which in late summer probably occurs at a depth of 20–25 m. On the temperature in Baltic lakes see further especially Halbfass (1901, p. 60), Ule (1898, p. 32), and Seligo (1905b, p. 201).

The *transparency*, which, as is well known, depends almost exclusively on the amount of material dissolved in the water, is always slight; greatest in winter (7–8 m.), less in summer (rarely over 4–5 m.): see Halbfass (1901, p. 78) and Ule (1892, p. 63). Seiches have been studied by Halbfass (1903b, p. 16; 1904, p. 65).

The *colour*[1] of the Baltic lakes is hardly ever blue, as it may be exceptionally in alpine lakes, the water of which is purer; it is rarely

[1] There is a long series of researches dealing with the colour of fresh water. The older literature is cited in Forel (vol. ii. p. 462). In recent times there are investigations by Spring (1883, p. 55; 1886, p. 814; 1896, p. 94; 1897, p. 578; 1899b, p. 99; 1905, p. 101); Klunzinger (1901, p. 321; 1902, p. 338); Ule (1892, p. 70; 1894, p. 1; 1901, p. 16a); Aufsess (1903, p. 1; 1904a, p. 186; 1904b, p. 678; 1905, p. 1).

There are two theories to explain the variations in the colour of the water—the one physical (diffraction theory), which maintains that the colour can be considered "*als Farbe trüber Medien*"; the other chemical, which considers the colour as a special property. The investigations of v. Aufsess, made for a great part in lakes under different conditions, specially show that the latter view is the right one. It is simply and solely the solution of different substances which are carried down to the lakes in various ways which gives the water a colour differing from the pure blue. The substances which cause variations in the colour are chalk and organic humous materials. Large amounts of chalk give a green colour; large quantities of dissolved organic substances vary the colour through green over to yellow. The green lakes occur chiefly in chalk areas; the yellow and brown waters are found especially in the regions where large masses of decomposing plant materials occur. It is in the first instance the geological nature of the lake-basin and of the lake's drainage area which determines the colour of the lake-water. So far as one can judge simply from observations of the colour of lake-water and from some knowledge of the geological nature of the drainage area, I may say that all I have seen on my numerous journeys most distinctly indicates that v. Aufsess's view is right. According to Bourcart (1906, p. 108), inorganic salts, especially calcareous salts, have no colouring influence at all. Ferric salts also may produce a change of colour, especially in bog-water (Spring, 1897, p. 578).

greenish-blue, but often green; the abundant supply of humic substances washed out of the ground by the rivers generally causes the colour to be of a more or less brownish tint, but hardly ever so intense as that of the Scottish lakes (see especially Ule, 1898, pp. 69–72). This brown colour is, so far as I understand, more conspicuous in North German and South Swedish than in Danish lakes, of which the larger, in my opinion, cannot be said to be brown but much rather green, perhaps owing to the great quantity of lime in the water. The brown tones of colour are most distinct in small lakes and in summer; the green colour in spring, soon after the ice has broken up. The influence of the plankton on the original lake-colour will be referred to later.

As to the *chemical* composition of the lake-water I need only refer to the greatly varying abundance of lime from lake to lake. The chalky nature of the surrounding country, of course, exercises a very great influence. The waters of lakes situated in moraine clay rich in lime have higher percentages of lime than those in territories with sandy ground. This zone, in contrast to the foregoing, may no doubt on the whole be said to contain many lakes having a high percentage of lime. Those which are remarkable for their greater transparency, purer water, and colours of a more greenish tinge have generally a richer organic life than waters with a small percentage of lime and coloured more or less brown by the humic acids. In describing the conditions in the Baltic lakes, and not least the chemical composition of the lake-water, it ought to be remembered that many of these lakes have formerly been in much more intimate touch with the sea than now. In the so-called beach-lakes the degree of salinity varies very much; even in the true inland lakes, where, of course, it is slight, it may sometimes exceed 10 in 100,000 parts (Halbfass, 1901, p. 90). Concerning the quantity of dissolved organic material little is as yet known; it is most probably on the whole pretty great—greater in shallow than in deep lakes, greatest in autumn and least in winter (Halbfass, 1901, p. 94).

The broad littoral zone is covered with vegetation, everywhere arranged in very uniform belts, first a belt of *Scirpus* and *Phragmites*, and then a belt comprising species of *Potamogeton* with *P. lucens* and *P. perfoliata* as main forms, and outside that again a belt of *Characeæ* mainly formed by species of *Chara* which hardly descends deeper than about 5–7 m.; a *Nitella* belt is absent or weakly developed, but amongst the Characeæ and also outside the latter we find a peat-forming community of sterile submerged mosses, in our lakes at any rate going out as far as 9 m., in South Swedish lakes as far as 7 m. (Carlsson, 1902, p. 27). The main forms are *Amblystegium scorpioides* and *Fontinalis antipyretica*. I have known this moss belt for a long time, though it has been little studied. Outside this belt, again, it has sometimes, but not always, been possible to find a so-called "Grundalgenzone" (Brand, 1896, p. 8). On the vegetation in the Baltic lakes see especially Warming (1897, p. 164), Ostenfeld (1905, p. 377), Baagöe and Kölpin Ravn (1896, p. 288), Carlsson (1902), Brand (1896, p. 1), Klinge (1890, p. 264). In the littoral zone we further find an extremely rich animal life. Many species of Mollusca with an enormous number of individuals are to be found, and enormous quantities of insects are also hatched there.

The lakes of this zone are specially characterised by the important part played by the organic life. It is not here, as in the other zones, the lakes which impose conditions to which the organisms must adapt themselves; it is the organic life which has got the upper hand of the lakes, transforming them through fundamental changes in the shape of the lake basins and in the chemical and physical qualities of the water.

Through the influence of the waves and the ice the material of the littoral zone which decays in autumn undergoes *pulverisation*. The detritus thus formed mixed with the large quantities of clay, lime, and organic material carried in by the rivers, together with the plankton, produce precipitation, filling up and transforming the original lake-basins. The lake-bottom is covered by enormous layers of material originally mainly organic, which through the action of the bottom fauna and bacterial flora is transformed into clay and calcareous gytjes. The filling-up process always begins in the primary inlets of the lakes, so that the lakes are rounded and approximate to the circular shape. The result of the filling-up process is the rapid closure of the lake-basins: one lake after another becomes closed; tracts of land rich in lakes become dry plains or give place to peat-bogs and meadows, a process which but rarely goes on so rapidly farther north. Owing to the large quantities of plankton, the nature of the bottom is to a great degree determined by the quality of the plankton (Diatom gytjes, Cyanophycea gytjes, Chitin gytjes; Wesenberg-Lund, 1901, p. 110).

The rich life of the littoral region further influences to a high degree the *thermic* conditions. The fact that the temperature of our lakes in summer can rise so high is due, I believe, to a very great extent to the organic life in the littoral region. On warm summer days temperatures of 30–35° C. may occur in the dark, warmth-abstracting, and warmth-producing heaps of detritus. Similar temperatures are also found in the *Sphagnum* and *Hypnum* moss-beds often found at the upper ends of the creeks in our large lakes, and also in the dense vegetation of *Myriophyllum*, *Hydrocharis*, and other plants which lie much nearer to the free surface of the water. That these beds of vegetation are able to collect considerable amounts of warmth is well known through Kerner's investigations, and the phenomenon has been described later by Brinkmann (1905, p. 27). Neither of these seems to know that the enormously high temperatures (30° C.) occurring in the upper layers of the vegetation are very distinctly limited to the surface; at about 1 m. below the surface the temperature is often only 15–18° C. Thrusting an arm down through such a Sphagnum-bed warmed by the sun, we get an intense feeling of cold in the tips of the fingers and a feeling of great warmth up at the shoulders. I believe that the great warmth which thus arises in the littoral region is carried by the waves, especially on days when the wind rises before cooling begins, out over the lake, and is of benefit to the surface of the lake. To demonstrate further the importance of the littoral zone as a warmth-producing factor, I give here some observations from recent years.

On 3rd March 1907, when Furesö was everywhere covered with about 12 cm. of ice, the temperature towards the shore in about 6 cm. of water about $\frac{3}{4}$ m. from the margin of the ice was not less than 7° C. (sheltered thermometer); bright sunshine, time from noon to 4 p.m. The air temperature in the shade was +0°·5 C.; at 5 p.m. the temperature of the water at the same place had gone down to +1°·5, the air temperature to −0°·5. Shortly after the free margin of water had certainly become coated with a thin layer of ice.

On 28th March 1907, when the temperature of the air in the shade at 2 p.m. was about 10° C., the temperature of the surface-water in Esromsö in the pelagic region was 2°·5. On the north coast of Nöddeboholt, close to the shore, exposed to the land wind from N.N.W., the temperature of the water was 5°·1; but on the south side, on the borders of the vegetation, in bright sunshine, 17°·2; in the ground only about $\frac{1}{4}$ m. from the water's edge, 7°·2 C. At the same time numerous bog-hollows in Grib forest were still covered with ice. In a Sphagnum-moss which was strongly lighted by the sun, and whose sides were completely frozen and hard as stone, the thermometer a few cm. below the surface of the Sphagnum-bed registered 12° C.

On 12th April 1906 one of the experimental ponds belonging to the Fresh-water Biological Laboratory was still covered with ice on the sheltered side and the margin frozen; on the opposite, sunny side the temperature was 7° C. On 29th March 1907 all three experimental ponds were on the sheltered side, which at this time of year never has any sunlight, covered by 6 cm. of ice. The temperature of the air in the shade was 11° C. at 2 p.m. The temperature of the water on the sunny side of the ponds, amongst the vegetation, was 14–17° C.;

at the margin of the ice, out towards the open water, 3° C. The temperature of the ground on the edge of the water, on the sunny side, was 12° C.

A continuous series of warm, bright days at the end of March (10–11° C. at midday) and in the beginning of April raised the temperature of the pelagic region in the small ponds unusually high (6–8° C.), whilst during the same period the temperature in the pelagic region of Furesö rose only 1°—from 2°·1 to 3°·1 in the course of four days, 28th to 31st March. In the following three weeks, when the temperature of the air never rose above 5°·6 C. and was generally lower, the temperature of the water in the ponds nevertheless steadily rose to 6°·7 C.; the surface temperature in the pelagic region of Furesö rose immediately after the above-mentioned warm days (28th to 31st March) to 4° C. and continued to rise to 5°·7, at which temperature the surface of the lake remained to the last days of May. These high water temperatures cannot possibly be due to the warmth of the sun at that time, as the air temperature was throughout lower than the water temperature. In my opinion, it was in the first instance the high temperatures occurring in the littoral region in very early spring which imparted a surplus of warmth to the pelagic regions of the lakes and ponds, a warmth retained later; and further, it was the warmth-collecting quality of the littoral region which absorbed every sunbeam cast upon it in the foggy, rainy April, that was later of benefit to the pelagic region. Various things seem to me to indicate that under our climatic conditions the monthly average temperature of the water in the summer months in the pelagic region of our lakes will be above the average temperature of the air. That, on the other hand, the littoral region becomes extremely cold during the period of cooling is a well-known fact which I need not discuss here. As I have the impression, however, that the importance of the littoral region as a store of warmth, at least in the Baltic lakes, is less well known, I have dwelt upon the subject here at some length.

What also acts in these lakes as a warmth-absorber, and, under the influence of the processes of putrefaction, as a warmth-producer, is the enormous quantity of plankton, especially during the periods of the water-bloom, which is produced in the lakes in the warm summer months. We have unfortunately no data to show how high these temperatures may rise.

Further, the rich organic life influences the *colour* of the water in the Baltic lakes; the true colour has, so to speak, never been seen, being almost always determined by the plankton, that is, by the particular coloured bodies in the plankton organisms which have their maximum at the moment in the lake (on this point see especially

Klunzinger, 1901, p. 321, and 1902, p. 338; also Zacharias, 1902, p. 700, 1903, p. 296). As these plankton organisms are different in the different lakes and vary during the seasons in each lake, the colour of the lake undergoes much greater variation than in other zones. We may say that as a rule the brownish-yellow Diatom-colour characterises our lakes in spring and autumn, the blue-green Cyanophyceæ-colour in summer; in cold and deep lakes the brownish-yellow colour is also preserved in summer, but this is due to *Ceratium hirundinella*. Sometimes other tinges of colour break in and replace the former quite suddenly and for a short time. Thus the Oscillatoriæ gave Furesö a whitish tint in May 1903, and the *Lyngbya* a cherry-red tint in September and October 1902. *Botryococcus Braunii* sometimes gives a reddish colour to several of our lakes. In mild winters the lakes keep the Diatom-colour. It is in early spring that the plankton has least influence on the colour, but even then the true colour of the lake is not apparent, as just at that time the huge masses of detritus give it a brownish or greyish tint. The true colour of the lake-water is most apparent in May, when the Diatom maxima are almost over and the large Cyanophyceæ maxima have not yet begun and the detritus has gone to the bottom (see Wesenberg-Lund, *Prometheus*, 1906, p. 785). An impression of the enormously large quantities of plankton which are developed, especially during the Cyanophyceæ maxima, is obtained by filtering the water, which then shows a faint milky colour, most probably caused by the Phycocyan set free in the processes of putrefaction. How far these observations from the Danish lakes also apply to the lakes in the remaining part of the zone is at present unknown. In North Germany, Ule and Halbfass have remarked upon the great importance of the plankton in determining the natural colour of the lake. Compared with the alpine lakes we may say that the Baltic lakes almost always have in reality "water-bloom."

The organic life, especially the enormous quantities of plankton, reduces also the *transparency*. The great yearly variations in transparency may always with certainty be traced back to corresponding variations in the amount of plankton. Whereas in the high-alpine lakes the quantities of detritus reduce the transparency, this is only to a slight extent the case at least in the greater part of the Danish lakes, except immediately after the ice breaks up and the drifting ice has scratched up the bottom. The quantity of plankton (water-bloom) may be so great that it acts as a wave-subduer. More than once I have seen a gale blowing the greater part of the water-bloom down into a corner of a lake, and in the centre raising high waves with spray; nevertheless on the windward side the surface was almost smooth, with but a long swell through the thick water filled with water-bloom.

The composition of the lake-water is also *chemically* influenced by the organic life. In summer, when the water is only to a very slight degree renewed and the evaporation is great owing to the high temperature, a further concentration takes place from the decomposition of the great quantity of organic material. The water, especially in the shallow lakes, thus almost assumes the appearance of soup, which is no doubt of the greatest importance in determining the maximum development of many Infusoria, Chlorophyceæ, Flagellata, and Myxophyceæ. The phytoplankton may play a principal part in the production of oxygen, probably to a less degree in lakes than in ponds (Knauthe, 1898, p. 785; 1899, p. 783). In bright sunshine the *Volvocineæ* and *Euglena* of the ponds can secrete such large quantities of oxygen under the influence of light that the water may contain up to 24 c.c. oxygen per litre. Corresponding quantities do not occur, indeed, in the lakes (9–12 c.c., Halbfass, 1901, p. 96). The quantity of oxygen does not, as a rule, attain in lakes the limit of saturation, or at any rate exceeds it but slightly (Halbfass, 1901, p. 96).

Within recent times the view has come more and more to the front that the reduction of the carbonic acid in lake-water, and therewith the deposition of lime, is in greater or less degree due to the activity of organisms. In fresh water these organisms are the green plants and molluscs. If the water at a given tension is saturated with calcium bicarbonate, then for every gram of carbonic acid which is taken by the plants during the assimilation processes from the water and used to build up organic materials, 2·3 gm. $CaCO_3$ are precipitated. The molluscs "absorb calcium bicarbonate, retain the monocarbonate, but the carbonic-acid-forming bicarbonate is liberated" (Krogh, 1904, p. 382).

Some authors are inclined to see in the action of the organisms the chief source of the reduction of the carbonic acid (Duparc for the lake d'Annecy, 1894, p. 199; Halbfass, 1901, p. 93, and Passarge, 1901, p. 144, for several North German lakes; and for the lower-lying alpine lakes, Bourcart, 1906, p. 118). A co-operating part in the reduction of the carbonic acid is ascribed to the organisms by Delebecque (1898a, p. 222; 1895, p. 790). Dr Krogh takes up a special position. He comes to the main result that the organisms "in the long run are altogether incapable of either adding to or diminishing the lime deposits in a lake" (p. 382). Krogh supposes, in fact, that nearly all the organic material of plants "is in due course again decomposed, whereby the carbonic acid is completely recovered"; for the molluscs, he maintains that the liberated carbonic acid "will increase the tension of the water, causing it to dissolve from the lime deposits of the bottom, from dead shells, and, indeed, from whatever source, exactly the quantity of lime which the living mussels have taken from it."

Within later years a long series of investigations have been published: Davis (1900a, p. 485; 1900b, p. 498; 1901, p. 491), Wesenberg-Lund (1901, p. 1), Passarge (1901, p. 79), Früh and Schröter (1904, pp. 196–199), Weltner (1905, p. 277), Steusloff (1905, p. 1), Marc le Roux (1907, p. 347). We have all arrived at the same result, that the lime deposits are due largely, if not entirely, to organisms. Passarge (1901, p. 144) even maintains that these can cause lime deposits on a large scale. Ramann at first seemed to take up a special position. He believes "dass die Seekreide aus der Zersetzung gelöster Kalkhumate hervorgeht welche dem Seewasser aus benachbarten Gebieten zugeführt werden" (1905–6, p. 161; 1905, p. 44; and 1906, p. 174). Ramann has accepted the explanation of the origin of the true lake lime given by Passarge and myself, but seems still to maintain his own with regard to "Wiesenkalk," which he is no doubt entitled to do. I hope, however, to be able to return to this explanation later. It must therefore be concluded that Dr Krogh at present stands quite alone with his above-mentioned views. In my plankton work (1908, pp. 291–293), to which I here refer, I have contested the views of Dr Krogh.

The "organism" which has probably most of all modified the natural conditions in the Baltic lakes is *man*. In thickly populated territories, where castles and monasteries were often built near lakes and where towns arose under shelter of the castles, where later on water-mills and factories were worked by the effluents and affluents of the lakes, the lakes were drawn into his range of interest. Originally they were only of importance to man as fishing-grounds, later he learned to use parts of their vegetation (*Phragmites* and *Scirpus*); but after having destroyed the stock of fish, and the lakes had become like dead capital on his acreages, he utilised them in another way. The great desiccation projects began, and lake by lake disappeared; in part through drainage, in part more indirectly through forest exploitation, a diminution of the lake area has in many places taken place. It must, on the other hand, be remembered that at possibly still more places man has kept the height of the water in the lakes above the normal level by means of locks and sluices. It is at any rate certain that the renewal of water in most lakes is dependent on the discretion of man. The comparatively small and shallow lakes with their often small affluents and outlets and their slight fall have made this possible. No less has he influenced the chemical composition of the lake-water. Substances alien to the latter (chlorine and ammonia) are in increasing quantities conveyed to it through the refuse from towns and the chemicals from factories (see especially Marsson, 1903, p. 60, 1904a, p. 1, 1904b, p. 125; Kolkwitz, 1905, p. 1, 1906, p. 370, with list of literature).

The Central European Alpine Lakes

In no other zone have the lakes been so closely studied as here; this is mainly due to Forel's fundamental investigations, but in addition to these we may also note the following works: *Austrian Alpine Lakes* (Richter, 1891, p. 189; 1897), *Halstättersee* (Lorenz v. Liburnau, 1898, p. 1), *The Lakes of Reschen Scheideck* (Müllner, 1900, p. 1), *The High Lakes of the East Alps* (Böhm, 1886), *The Lakes of the German Alps* (Geistbeck, 1884–5, p. 203, with list of literature), *Starnbergersee* (Ule, 1901, p. 1), *Lakes of Jura* (Delebecque, 1898a, and in many small papers), *The Swiss Alpine Lakes* (Zschokke, 1900; Bourcart, 1906; Bachmann, 1907, p. 1), *Zürich* (Pfenninger, 1902, p. 1), *Vierwaldstättersee* (Amberg, 1904, p. 1), Montiggler Lakes (Huber, 1905), *Lac d'Annecy* (Marc le Roux, 1907, p. 220), *Schoenenbodensee* (Tanner-Fullemann, 1907, p. 15), *Bodensee* (Bauer and Vogel, 1894, p. 5; Klunzinger, 1906, p. 97, etc.).

In these, and in a very great number of smaller, partly planktological papers, we find exceptional material to judge of the general physical conditions in these lakes. Only the following more general characteristics need be mentioned here.

The height above the level of the sea differs greatly; the great majority are over 400–500 m. above sea-level, thus at least three times as much as the majority of the Baltic lakes. A great many are in the regions of perpetual snow. The country surrounding the lakes is frequently covered by glaciers, but mostly consists of mountain slopes, forest ground, and to a less degree of arable land. The rivers hollow out their beds mainly in solid rock, not in loose, easily movable kinds of soil.

The lower-lying alpine lakes are often remarkable for their considerable size and their elongated, often irregular shape and considerable depths of 100 m. or more. The high alpine lakes are relatively small, with slight depths, often under 40 m., and mostly much shallower. It is principally the greatest depth which is slight; the mean depth (the relation between the volume and area of the lake) is on the other hand often great in high lakes (Bourcart, 1906, p. 104). The littoral zone is generally narrow; the shores are frequently formed of high, steep mountains, rising abruptly from the lake, with great depths near land; it is mainly in front of the river mouths that we find more evenly sloping shores (deltas). The primary lake-bottom is probably everywhere covered by soft bottom deposits, less rich in organic material than in the foregoing zone, but chemically varying according to the nature of the surrounding country—very calcareous in the lakes of the Jura mountains, poor in lime especially where the lake is fed from melting snow.

The *height* of the water undergoes very considerable variations in the course of the year, especially where the lake is fed from melting snow; the renewal of the water proceeds unequally at the various seasons—most rapidly in spring, when immense quantities of water during thaw pour into the lakes. Owing to the great evaporation in summer and the decrease in all affluents the level of the water sinks greatly; the degree of concentration combined with great but regular variations in transparency, colour of water, etc., therefore undergoes considerable oscillations. On the great changes in level in the high alpine lakes see Zschokke (1900, p. 17).

Information regarding the *temperature* in many lakes of this zone is to be found in numerous records of many authors. It is not my intention to give here a summary of our knowledge of lake temperatures in general, but merely to emphasise those features which are characteristic of the lakes in each zone. After having studied this literature, it has, however, been impossible for me, apart from the little advanced here, to discover any features which might be said to characterise the alpine lakes in contrast to the Baltic lakes.

Temperature varies greatly, of course, but presents, on the other hand, a certain amount of uniformity hitherto hardly sufficiently noticed. There are lakes which must be designated as completely arctic, frozen even in the middle of summer or with masses of ice floating on their surface and the summer temperature hardly exceeding 2–3° C. Such lakes are mentioned by Monti: Lac de Séracs (at a height of 2370 m.; the surface was in September covered with ice, and the temperature at surface was only 2° C.; 1906, p. 131), Lac de Grand-Doménon in the massif of Belledonne (Delebecque, 1898a, p. 170), Lac d'Arrius (Delebecque, 1898a, p. 171). The lake of St Bernard hospice, at a height of 2445 m., is closed up in certain years for 330 days: it closed on the 22nd October and was not open till the 15th September (Zschokke, 1900, p. 35). The majority are no doubt temperate lakes, but approach the arctic type more or less: there are lakes which one year may be designated as arctic, in others as temperate. Concerning all these lakes there is much extremely interesting information in Zschokke's excellent chapter on temperature in high alpine lakes (1900, p. 20). In the same zone in which we find these lakes, situated under more or less arctic conditions, the temperature of which at any rate in certain years does not exceed 4° C., we find distinctly tropical lakes which never freeze—Lac Léman (Forel, vol. ii. p. 395) and the North Italian lakes—or only exceptionally—Bodensee, seven times since the year 1227 (Geistbeck, 1884–5, p. 364)—or only exceptionally and in part—Vierwaldstättersee (B. Amberg, 1904, p. 142). However much all the lakes of this zone differ in regard to winter temperatures and ice conditions, their summer temperatures are somewhat similar. This is never appreciably high, and the great variability which might be expected in lakes of which some are of the conspicuously tropical type, others, owing to the exceedingly long duration of the ice-covering, almost of the arctic type, is not met with. Neither Vierwaldstättersee (Amberg) nor the Lake of Zürich (Pfenninger) generally exceed 22° C. even in the warmest summer time, Lac Léman at most 23° C. Lakes under even almost arctic conditions may, on the other hand, have temperatures which, though of brief duration, are high (12–15° C.) (see Zschokke, Pitard, Monti). Even in lakes frozen during about 300 days in the year, the summer temperature still attains 6° and probably more. The reasons for the comparatively slight difference in summer temperature are principally that the affluents are to a pretty considerable extent derived from glaciers and thus everywhere carry very cold water, that the littoral zone, which in the Baltic lakes plays the great heating part, is of small extent in the alpine lakes, that the organic processes in these do not work with such an intensity as to raise the temperature, and finally, that many of the less highly situated lakes and those from which we have most information are very large lakes with great depths, while the high alpine lakes are small and comparatively shallow lakes. Zschokke maintains, as the result of the records of the temperature in lakes over 1500 m. above sea-level, that the summer temperature does not exceed the deep-lake temperature in the less highly situated, somewhat large lakes; still, I think that it might also be emphasised as a biological factor, that these high alpine lakes so often attain relatively high temperatures. Whether the latter temperature extends over short or long periods is of slight importance: the main point, according to my opinion, is that the temperature is reached. One thing is at any rate certain: all differ from the Baltic lakes in having a lower summer temperature (even in the larger of the latter lakes this is often about 24° C.); further, many of them have a much smaller range of temperature variation. In Lac Léman it is, for instance, only 4–22° C., in the high alpine lakes rarely over 0–12°, in the Baltic lakes 0–25°. Finally, it may be emphasised that the warming up and cooling in the various lakes, according as these approach the tropical or the arctic type, differ greatly, and that the length of the summer and the winter periods of stagnation respectively, as well as of the periods of circulation, must likewise vary much more in the lakes of this than of the other zones.

The water is on the whole remarkable for its great *transparency*; in the Lake of Geneva the white disc has been visible even at a depth of 21 m. in February, in July at a depth of only 4 m. (Delebecque, 1898a, p. 179). The mean for transparency in the Lake of Geneva is 10·2 m., in Vierwaldstättersee 9·4 m., in the Lake of Zürich 6·5 m., and in Bodensee 5·4 m. (Amberg, 1904, p. 73; see also Geistbeck, 1884–5, p. 387). In the high alpine lakes also the transparency may be very great, up to 22 m. (Delebecque, 1898a, p. 185); but in the majority it is much less. It must, however, be kept in mind that the transparency has nearly always been measured in summer, when, as a matter of fact, it is least. In the Montiggler lakes, Huber (1905, p. 43) has shown that the transparency of the water is greater in summer than in winter. Rivers coming directly from glaciers carry immense quantities of pulverised material into the lakes; in this case the lakes have milky water and are but slightly transparent (Bourcart, 1906, p. 107). Of the wonderful crystalline ice of the alpine lakes, and the very great depths at which the pebbles of the bottom may be seen, we have many records (see Geistbeck, 1884–5, p. 368).

The *colour* of the water is, as is well known, blue, bluish-green, or green; but the blue lakes, those which have 1–4 in Forel's scale, are rare (Lake of Geneva, d'Annecy, etc.). The majority are green, Forel's scale 5–9 (Lake of Zürich, Vierwaldstättersee bluish-green; for the rest I may refer to Amberg, 1904, p. 80). Yellowish-brown lakes also occur, not rarely with colours exceeding Forel's No. 9 (Forel, Delebecque, Bourcart).

With regard to the *chemical* nature it need only be mentioned here that Bourcart has clearly shown the close agreement between the petrographic nature of the surrounding country and the chemical composition of the lake-water (1906, pp. 120–127; see also Delebecque, 1898a, p. 205). Zschokke (1900, p. 38) records that high alpine lakes, owing to the lower atmospheric pressure and the slight vegetation, are of themselves poor in oxygen, although the mountain brooks supply somewhat the want in this regard. The absence of outlets from factories and on the whole of detritus of every kind, and thus of all oxidisable substances, has the effect, on the other hand, that the loss of oxygen during the oxidation processes is slight.

The organic life of the lakes does not influence the physical and chemical qualities of the water in the alpine lakes, nor the filling up of the lake-basins, nearly so much as in the Baltic lakes. The plankton only exceptionally determines the colour of the water (*Oscillatoria*), and has hardly any appreciable effect upon the nature of the bottom, as is often the case in the lakes of the Baltic zone (Chitin-, Diatom-, Cyanophycea-gytjes), but influences certainly to a considerable degree the transparency. In the high alpine lakes the quantity of plankton is, as a rule, small; still, even high alpine lakes may be very rich in plankton (Zschokke, 1900, p. 302), but this is then thought to be due to abnormal phenomena (affluents from the St Bernard hospice).

The steep coasts prevent the occurrence of the broad vegetation belts which are so characteristic of the Baltic lakes; the conditions for the *Scirpus-Phragmites* growths especially are in numerous cases not present; on the other hand, the outermost vegetation belts, especially the *Characeæ*, with a fairly well-marked *Nitella* zone of 13–30 m., reach much greater depths than in the Baltic lakes (Lake of Geneva and Bodensee.) The higher we go up the mountains the more the importance of the vegetation belts as nutrition for the animals decreases (Zschokke, 1900, p. 14). In lakes above 1600 m. they generally play a secondary part. Yet *Potamogeton*, *Sparganium*, and especially *Batrachium* grow as high up as 2100–2500 m. A very great part of the vegetation in the high alpine lakes is for the rest made up of Characeæ; where these are absent Confervaceæ, Diatoms, and Desmidiaceæ, in addition to the phytoplankton, are in the majority; they form the "Feutre organique" (Forel, vol. i. p. 119, Lake of Geneva), "Gefilz" (Lorenz v. Liburnau in *Hallstättersee*, depth of 40 m., 1898, p. 189), "Grundalgenzone" (Brand, *Starnbergersee*, 1896, p. 8). Zschokke records that these algæ coverings in the high alpine lakes are of all the more importance as producers of oxygen, as the water above 1800 m., according to Boussingault, only absorbs, as stated above, small quantities of oxygen, owing to the diminished atmospheric pressure.

The main work on the flora in the alpine lakes of this district is Magnin's *La végétation des lacs du Jura*, 1904. The belts are the same as in our lakes: the *Scirpus-Phragmites* zone, the *Nuphar-Potamogeton natans* zone, the *Potamogeton lucens-perfoliatus* zone, the *Characeæ* zone. As specially characteristic of the lakes of Jura, Magnin mentions the great development of a *Nuphar* zone (pp. 374, 408). He further remarks on a considerable difference between the flora in lime districts, specially characterised by many *Characeæ*, and in the silicate districts, and maintains that not only the *Characeæ*, but also the *Potamogeton*, attain their greatest development in high mountain lakes, not in the less highly situated lakes.

Even if the organic life is instrumental in causing the decalcification of the lake-water and the richness in lime of the lake-bottom, it is hardly of so great importance here as in the Baltic lakes: in part owing to the lower summer temperature, in part because a much greater amount of the organic material of the lake is destroyed in the lake itself and again acts, through the carbonic acid set free during the destruction processes, as lime dissolving. The blue-green algæ especially (Lake of Geneva, Neuchatelersee, Chodat, 1897, p. 289, 1898, p. 49; lac d'Annecy, Le Roux, 1907, p. 347) and the Characeæ seem to play the most prominent part as decalcifiers.

It must be said that, as a rule, the deposits derived from plankton and from the littoral region are not nearly so instrumental in closing up the lakes as in the Baltic region. The filling up and the disappearance of the lakes proceed more slowly in the alpine than in the Baltic lake-area, and are most probably due more to the material carried along by the rivers, which is mainly inorganic, than to the organic material produced in the lakes. It appears, however, from Böhm's records, that the alpine lakes also disappear, that in the Tirol 118 alpine lakes have disappeared since 1774; and from Walser's, that of 149 lakes in North-East Switzerland 75 smaller ones have quite disappeared and 16 have been greatly reduced since 1668, in the course of about 250 years (*vide* Huber, 1905, p. 1; see also Früh and Schröter, 1904, p. 20). The influence of man on the filling up of the lakes and on the chemical quality of the water is probably hardly so great as in the Baltic lakes.

It appears from the foregoing that the alpine lakes present much greater similarities with the North European and arctic lakes than with the lakes of the Central European lowland; a detailed demonstration of this is quite superfluous. A great many phenomena which we have been able to record from the alpine lakes may certainly also be pointed out in the North European and arctic lakes, but have not been dealt with here, as we do not know anything as to their transparency or colour. The agreement of the physical conditions in the high alpine lakes with those in the arctic lakes has sufficiently often been advanced, recently by Zschokke; in most regards they also present quite the same appearance. Still, in one regard which has hitherto probably not been sufficiently emphasised they differ greatly, viz. in *light*. The long dark arctic winter night is not paralleled by anything in the high alpine lakes: the yearly quantity of light received by the alpine lakes is many times greater than that of the arctic region. In those cases where the high alpine lakes are covered with ice but free from snow, or where the snow does not cover the whole surface, this much greater quantity of light will, at any rate for the phytoplankton, be a principal factor in rendering active life possible where it is impossible in arctic regions.

Tropical Lakes

Omitting the Mediterranean lakes, since only future investigations can show whether these are to be regarded as a special type, we may briefly deal with the tropical lakes.

We may first of all mention the enormous quantity of light which penetrates the surface of the water, and also that the amount of light as compared with that in higher latitudes is not subject to such great and regular annual variations as is the case in the temperate and especially the arctic regions. Further, it must be remembered that the annual range of temperature variation is probably relatively slight—

much less than in the temperate zone, where it reaches from below zero to about 30° C. In no other part of the world, except perhaps the arctic, will we find lakes with such small annual temperature variations as in the tropics. Owing to the high temperatures, the evaporation from the surface and the drying up of the rivers in the dry season will produce great concentration of the water and great variation in its level. In the dry season large water-basins will be dried up, and in the rainy season again filled with water. The heavy rain in the rainy season will, owing to the enormous amount of decaying organic material, carry vast quantities of suspended material into the lakes, which, combined with the great quantities of organic material held in solution in the water owing to the high temperature, will produce the dark-coloured water which characterises so many of the tropical fresh-water lakes.

We have now endeavoured to obtain, as far as possible, an insight into the variations in fresh-water lakes from the pole to the equator. I wish further merely to call attention here to a physical phenomenon of the fresh-water lakes which has only come to light during the last few years. It is a well-known fact that the specific gravity and the viscosity of the water vary in accordance with the temperature. At 25° C. the viscosity of pure water is just half as great as at 0°; the specific gravity varies in accordance with the viscosity, but in a much less degree. Quite provisionally we may suppose that the viscosity of the fresh water is reduced concomitantly with the rising temperature in the direction from north to south, and undergoes the greatest regular annual variations in that zone, *i.e.* the temperate zone, where the annual variations in temperature are greatest. It is evident that the variations in viscosity and specific gravity, since the supporting power of the fresh water, and therewith the conditions for buoyancy, are dependent on these variations, are of the greatest importance to plankton organisms.

In accordance with the plan laid down in the beginning, we shall now consider the communities of plants and animals in fresh-water lakes and their variations in the higher latitudes. In fresh-water lakes we may distinguish between three great communities: the littoral, the abyssal, and the plankton communities. Of the abyssal communities in the fresh water we know very little; they very probably contain many cosmopolitan species, but Lovén's explorations in the Swedish lakes, the Russian investigations in the Baikal Lake, and Moore's in the African lakes have shown that the abyssal fauna of the fresh water contains many very peculiar organisms, more definite knowledge of which will have to be obtained from future investigations.

With the littoral communities we are best acquainted. Hitherto no one has tried to bring together what is known regarding the changes these communities undergo systematically and biologically in the direction from north to south, nor can we attempt to do so here in this brief sketch. We shall restrict ourselves to remarking merely that these communities follow the same laws which control the life of land and sea. They reach their highest development in the tropics; for every latitude from north to south we meet with new types both in the vegetal and in the animal kingdom. Still, it must be maintained that the littoral fauna and flora of fresh water, especially amongst the lower organisms, contain many cosmopolitan species, and that even amongst the higher a great many enjoy an extremely wide distribution.

With regard to the plankton communities our knowledge until about 1890 was very insignificant. In the last twenty years the investigation of the European fresh-water plankton has been carried out with great energy; some knowledge of the arctic and the tropical fresh-water plankton (especially that of the great African lakes) has been gained.

During the last ten years I have been much occupied with plankton studies, and in my work on *Plankton Investigations in the Danish Lakes*, 1904–8 (Copenhagen), I have endeavoured to bring together all that could throw light on the life-histories of the plankton forms. In the following, in accordance with Sir John Murray's wishes, I shall try to give the main points of these investigations, taking as my starting-point one of the greatest peculiarities of the fresh-water plankton, viz. its cosmopolitanism. From this as basis and as a means to understanding the nature of this cosmopolitanism the opportunity is afforded of mentioning the lines of investigation which have in recent years specially occupied the investigators in this great field of work.

PART II.—THE PLANKTON COMMUNITIES, THEIR GEOGRAPHY AND LIFE-HISTORY

The fresh-water plankton is characterised by its well-marked cosmopolitanism. I consider this cosmopolitanism as an established fact for a great many plankton organisms, and I believe that it can be seen with distinctness from most of the plankton papers of recent times. This subject has been more closely discussed in chap. xii. of my *Plankton Investigations*. In their interesting work, *The British Fresh-water Phytoplankton*, 1909, chap. xii., Messrs West have maintained that it does not hold good for the Desmidiaceæ. It may be remarked, however, that a very large number of these can only with difficulty be regarded as true plankton organisms, especially the true, typical lake plankton which was exclusively in my mind. Further, it must be remembered that by far the greater part of our knowledge of the Desmid flora, and especially of the tropical, is based upon Messrs West's own excellent investigations. Other times may come and other investigators whose detailed views of species may perhaps not be the same as Messrs West's; it is thus quite possible that the boundaries between the regions given by Messrs West will be abandoned.

Against my opinion it can further be said that in the high arctic zone some types are apparently absent, that the great African lakes are characterised by their remarkable Diatom plankton, and that some few genera and species (*Sida limnetica*, *Limnosida frontosa*) are restricted to rather limited areas; only the Diaptomidæ, according to our present classification and knowledge, seem to have a distribution which is fairly sharply delimited for each species.

It must be emphasised that the fresh-water plankton communities, in contrast to all other communities on land or in water, everywhere contain the same types, nearly everywhere the same species. The arctic or North European zone and the tropical zone have a very large number of species in common. This applies especially to the *Diatoms*, *Cyanophyceæ*, *Chlorophyceæ*, and *Flagellata*; further, amongst the Rotifera, *Anuræa aculeata*, *Polyarthra platyptera*, *Asplanchna Brightwelli*, *Triarthra longiseta*, species of the genera *Branchionus*, *Pedalion*; amongst the Cladocera, *Bosmina longirostris* and *B. coregoni*, *Ceriodaphnia cornuta*, *Daphnia hyalina*, *Chydorus sphæricus*; amongst the Copepoda, *Cyclops serrulatus*, *C. Leuckarti*, *C. oithonoides*, etc. In no other community is so great a number of species common to the whole world: only very few new types are found on comparing the plankton of northern latitudes with that of southern. Considering to what a degree the different plant and animal communities, terrestrial as well as marine, change from the pole to the equator, and how no end of new types appear for every degree of latitude as we proceed to the south, the cosmopolitanism of the fresh-water plankton must first and chiefly be emphasised as its greatest peculiarity and one of its greatest puzzles, which we are at present unable to solve with certainty. The phenomenon is confirmed by every new research; future investigations may indeed increase the number of exceptions, but the fundamental result of this review will hardly be changed.

Compared with this phenomenon, the supposed maintenance of sharply delimited areas of distribution for certain fixed genera and species is of quite secondary importance. If we try by means of such areas, which appear at present apparently natural and well defined for some species within certain groups of animals, to divide the fresh-water plankton into similar well-marked zoo- and phyto-geographical territories like those of other communities, we find that the attempt quite fails.

Another very peculiar fact connected with the above-mentioned is that the almost inconceivable richness of forms which characterises all communities, both terrestrial and marine, in the tropics, has no parallel in the tropical plankton. It seems as if the greatest development of the fresh-water plankton is much more to be sought for in the temperate zone.

Explanation of the Cosmopolitanism

As is well known, many scientists explain the cosmopolitanism of the fresh-water plankton as having resulted from passive migration. As distributing agencies birds, wind, and the currents of the ocean are principally mentioned. These means of migration may of course be of some moment, yet I wish to call attention to a fact which has hardly been taken into due consideration, viz., that they can only be of any importance when acting over immense periods of time. With regard to plankton it must especially be remembered that its resting organs, the organs supposed to be transmitted by the above agencies, are wanting over large areas, which further diminishes the probability of passive migration with regard to lake plankton throughout great parts of the world. All in all, the supposition set forth by many authors, that the migration by means of wind, waves, and birds is taking place with great intensity, must, according to my view, be considered as untenable. The quantity of live germs which are transported by the above-mentioned agencies to new localities and there germinate and acquire new areas for the species is probably only slight. With regard to birds it must be kept in mind that they migrate on an empty stomach, and that migratory birds are almost always clean when they journey (Andersen in Ostenfeld, 1901, p. 116). Too much stress has been laid upon the few instances in which fresh-water organisms have been found attached to the feathers and feet of birds. In contradiction to the signification attributed to water as a distributing factor, speaks the well-known fact that lakes lying on a line and fed by the same river often exhibit quite different plankton communities. This especially holds good with regard to the zooplankton. In my opinion, none of the means of distribution at the disposal of this plankton which we know of at present can explain its enormous distribution. Only one factor, viz. *time*, can perhaps give us a suggestion as to the correct interpretation of the phenomenon.

Until the facts give some other explanation, I have formed the picture that this same fresh-water plankton, which in a horizontal direction has at present a more uniform appearance than any other community, has also vertically presented the same appearance during all times. *The fresh-water plankton is amongst the oldest communities of the earth.* The researches of recent times have shown us what an enormous part the plankton plays as fundamental food-material for the animal life in the water. To assume that the waters of the past did not contain the same fundamental food-material would lead to the most absurd consequences.

The reason for this food-material having on the whole remained unchanged from the oldest times until now is, in part, that it has been in a less degree than any other community exposed to complete extinction and new formation consequent upon the great convulsions of the earth; in part also, because of its powers of spreading, by means of which it would be able to recapture the areas from which it had been driven at any time.

That this community has contributed much towards the formation of the crust of the earth (limestone, petroleum, etc.) is certainly incontestable; that its particular forms have not been able to persist permanently owing to their delicate skeletons, upon which their occurrence as plankton organisms always depends, is by no means unnatural. In several cases, however, it has been supposed that either the plankton organisms or forms nearly related occurred in very old deposits. Thus, the blue-green algæ *Girwanella problematica* (Silurian), which together with other Cyanophyceæ are said to form the oolitic structure of rocks (Ordovician age in the Girvan strata); the *Peridinium pyrophorum* described by Ehrenberg from cretaceous rocks, which seems hardly to be distinguished from *Peridinium divergens* of the present day; *Coccospheres* and *Rhabdospheres* in the Lias deposits; the large Diatom deposits from the tertiary and cretaceous series, but curiously enough not from earlier deposits (see Seward, 1898, p. 117)—all these indicate that it is only to the lack of investigations and the nature of the material that our slight knowledge of fresh-water plankton in earlier times is due.

Further, it must be remembered that numerous forms of the bottom and littoral fauna and flora to which the plankton organisms are related are extremely old forms. We need only mention the Ostracoda of the palæozoic times. Nothing in the structure of the Daphniæ justifies us in considering these as much younger than the Ostracoda, their nearest relatives. That the Daphniæ appear only in the upper Miocene mud deposits from the old lakes in the Egerer and Falkenauer basin is certainly due, in part, to the preservation of these forms being much more difficult, and in part to the ephippia having been misunderstood (see also Brehm and Zederbauer, 1906b, p. 477).

If future researches raise the hypothesis that the fresh-water plankton of the world is collectively a cosmopolitan community to a scientific theory, the explanation of this should be sought for in the immense age of this community. With this view in mind, we may attribute to the birds, wind, and water a greater importance as disseminating agencies.

Means by which the Cosmopolitanism has been brought about

I. Different Modes of Reproduction.—If it should now be asked, What means do the species possess to enable them to adapt themselves to the varying and different demands imposed upon the individual organisms, partly in Greenland, partly in the large African lakes, attention must specially be directed to the following points.

It may be regarded as a well-known fact that a great part of the lower fresh-water fauna and flora, and probably more than we know of at present, have special resting-stages in which the species remains under unfavourable conditions; *e.g.* resting-cells in Cyanophyceæ, resting-spores in Diatoms, cysts in Chlorophyceæ, Flagellata, and Infusoria; resting-eggs in Rotifera, Cladocera, and Copepoda. In many cases these resting-stages proceed from special modes of reproduction; a great many plankton forms have several, generally two, modes. It further appears that the plankton forms employ the different modes of reproduction to a different degree in different climates: in certain zones one kind of reproduction prevails, in another, the other. In arctic regions reproduction in the Cladocera is only to a slight degree parthenogenetic, and is mainly digonic; the farther south we go the more parthenogenetic reproduction prevails, and the "sexual" becomes restricted to certain short periods. Quite the same thing is probably also displayed in the Rotifera. It is also certain that if the conditions differ very much in different localities, though in the same latitude, then reproduction also differs in these localities. In arctic regions reproduction is the same in pools and lakes, whereas farther south it differs in lakes and in ponds even for the same species. The pelagic races in the south pass from being dicyclic in ponds to monocycly and thence to acycly in lakes. The tendency to acycly increases in the pelagic races from north to south. *D. hyalina* and the *Bosminæ* are everywhere monocyclic in arctic regions; in the Baltic territory *D. hyalina* is dicyclic in ponds, at any rate in certain districts; in the lakes there is a decided tendency to acycly; in the lower-lying alpine Swiss lakes *D. hyalina* is distinctly acyclic, in the high alpine di- or mono-cyclic. Though not so conspicuous, very similar phenomena have been discovered in the Rotifers, and the very same can also be pointed out for many other lacustrine (bottom and littoral) groups of animals, in which either two sorts of eggs are met with (thick-shelled resting-eggs and thin-shelled summer eggs), or in which various modes of reproduction occur, the digonic or monogonic (parthenogenesis, gemmation, partition). The two modes of reproduction are not equally common under all climates and in all localities. For the Ostracoda, Bryozoa, Planaria, Dinoflagellata, and possibly also Phyllopoda I shall here not enter into more thorough details, but refer the reader to the following literature:—Ostracoda (S. Jensen, 1904, p. 21); Bryozoa (Wesenberg-Lund, 1896b, p. 350, and 1907, p. 71); Planaria (Zschokke, 1900, p. 86; Thinemann, 1906, p. 68; v. Hofsten, 1907, p. 4; Steinmann, 1906, pp. 199 and 213; and to valuable papers by Voigt); *Ceratium hirundinella* (Zederbauer). In certain latitudes and under certain conditions monogonic reproduction prevails; under others, digonic reproduction. This phenomenon, which, so far as I know, has hitherto not been sufficiently noticed in the animal kingdom, is exceedingly well known in plants. It is well known to all botanists that numerous plants under certain conditions and in certain latitudes only have vegetative reproduction, and that different conditions determine vegetative reproduction. It is just in the varying modes of reproduction and the ability the organisms possess of utilising mainly sometimes the one sometimes the other, that we must seek for one of the main causes of the quite phenomenal power of adaptation and the consequently wide geographical distribution of the plankton organisms (see Wesenberg-Lund, 1907, p. 70). It must be regarded as a well-known fact that the maxima of the plankton organisms seem to occur at certain fixed temperatures. If the temperature of the lake is too distant from these, the plankton organism concerned does not occur there (Cyanophyceæ rarely in high arctic lakes); if the right temperatures only prevail for a short time, the organism remains in resting-stages throughout the greater part of the year; where they prevail for a long time the resting-stage is but short. In arctic regions *Ceratium hirundinella* is only free and pelagic during a few weeks of the year; in the Baltic lakes, from April till October; in the North Italian lakes it is perennial. *Daphnella* does not occur in arctic lakes; it is a periodical form in the Baltic lakes, perennial in the Italian lakes; *Anabœna circinalis* is periodical in Danish lakes, perennial in the Swiss lakes. The duration of the resting-periods decreases towards the south, and in this we find an interesting parallel to the life of higher plants in different zones. We are thus able to show that the different use of the two modes of reproduction, the result of which is the different sort of eggs, germs, etc., is one of the chief means by which the plankton organisms are able to adapt themselves to the varying conditions in the different parts of the world.

II. Variation.—A second fact on which the cosmopolitanism of the plankton organisms depends is the extraordinary capability each species has of changing form. It is therefore necessary shortly to deal with our knowledge regarding the variation of the plankton organisms. The theories and suppositions set forth in the following are based upon abundant material: here, of course, only the main points can be advanced; with regard to all details I may refer to my main work.

1. *Seasonal Variation.*—The plankton organisms of the fresh water may at different seasons have quite a different appearance. This fact is, in my opinion, connected with the above-mentioned regular oscillations in viscosity and specific gravity of the fresh water. As the rate of sinking at 25° C., *i.e.* in the summer, is probably twice as great as in the winter, the organisms, unless they are able to augment their buoyancy in the summer half-year, will sink down into deeper water-layers; thereby they will be shut out from the light and high temperatures which for other reasons form a life-condition for them.

We are now able to show that very many plankton organisms, and especially the perennial, are subject in the course of the year to regular morphological variations which are exactly in accordance with the variations in the bearing power of the fresh water. As far as we are able to understand these variations, it seems as if the organisms, by means of either an increase in the cross-section resistance or an increase in the superficial area by diminution of volume, try to diminish the rate of sinking, and that just in the season (summer) when the rate of sinking is greatest. These variations of the fresh-water plankton organisms we call "*seasonal variations.*"

We may now mention some examples.

It has been noticed that the Hyalodaphniæ (fig. 52 [1]) in the summer half-year increase their longitudinal axis to a very high degree. While the distance from the eye to the point of the crest in the winter half-year is only about 100 μ, it is in summer up to 700 μ. The most correct interpretation of this very peculiar fact is probably that the prolongation of the crest causes a shifting of the centre of gravity of the body; the effect of this again is that the original vertical axis, with each beat of the swimmerets, becomes the horizontal, the result of which is an increase in the cross-section resistance. In other Cladocera (*Bosmina coregoni*, fig. 53) the body in the summer half-year is higher than long, in the winter half-year longer than high; in summer the antennæ are more than twice as long as in the winter half-year. In some Rotifers (*Asplanchna*, fig. 54) it is known that the body, which in winter is almost isodiametric, is in summer about five times longer than broad. Here the aim is probably to remove the shape of the body in summer as far as possible from the

[1] With regard to the figs. 52–62 it must be remembered that the size of the figures is quite conventional; the same species is in the different figures drawn in different sizes, and young brood and growth stages are often figured larger than mature animals.

spherical form and make it cylindrical or torpedo-like, since the cylindrical form, supposing that the body is held horizontally during sinking, is able to afford a greater cross-section resistance than the spherical. Some flagellates (*Ceratium hirundinella*) project horizon-

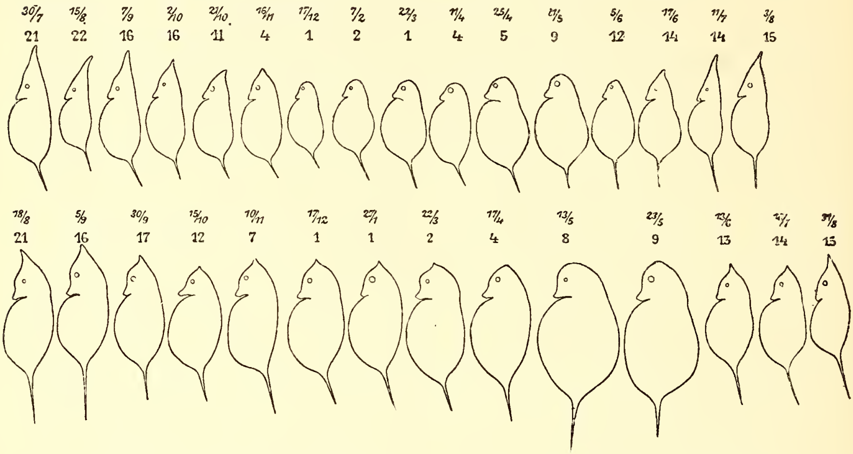

FIG. 52.—Seasonal variation in *Hyalodaphnia cucullata* (Furesö) and *Daphnia hyalina* (Esromsö). The two may best be regarded as two races (modifications, phenotypes) of the same species. In summer the crest is much higher than in winter, and the whole form more slender. The upper row of figures gives the date, the lower the temperature of the water in degrees C.

tally from the side of their body a long spine which, as it is inserted at right angles to the direction of sinking, augments the cross-section resistance. Very many organisms belonging to all the animal

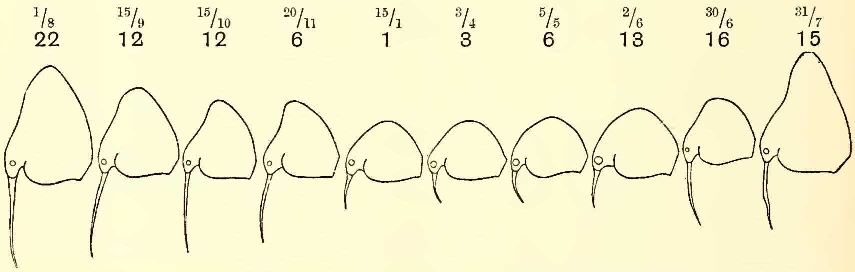

FIG. 53.—*Bosmina coregoni*, seasonal variation (Julsö). In the summer half-year the animal is higher than long; in the winter half-year, longer than high; the antennæ are more than twice as long in summer as in winter. The eye is largest in winter. This seasonal variation we do not understand.

plankton groups try, through diminution of the volume, to augment the surface. In this case the surface is often covered with a coating of small asperities; also by this means a diminution in the rate of sinking is probably attained.

Even if the physical interpretations are not in all cases quite satisfactory, one thing is at any rate quite unquestionable: the structures they are intended to explain are indisputable facts; that the plankton Daphnids, for example, are longer and narrower in summer than in winter is a fact beyond doubt. The plankton investigations have further given the following very interesting result. During the formation of all those structures on which the increase in the buoyancy power depends, all plankton organisms *follow parallel lines.* However different their organisation may be, the development of the buoyancy apparatus takes place *simultaneously* (May, June); *they reach their extreme development simultaneously* (mid-summer), *and they are reduced simultaneously* (October, November). From this, and because the highest development of the buoyancy apparatus unquestionably takes place just at the season when the rate of sinking is highest (summer), we conclude that *the variations in the buoyancy or supporting power of fresh water, following the variations in temperature, are the outer inducements which lead to the seasonal variations as the answer to these*

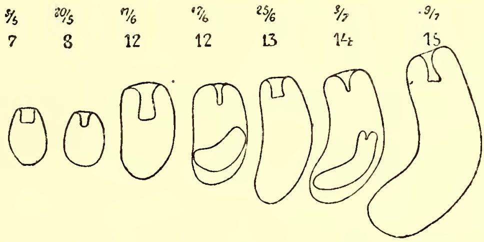

Fig. 54.—A Rotifer, *Asplanchna priodonta.* In May, almost isodiametric; in July, four times longer than broad.

on the part of the organism. The variations in viscosity and specific gravity on the one side and the seasonal variations on the other stand in the relation of cause and effect. In 1900,[1] when this theory was set forth, we had not the slightest idea of the manner in which the variations took place. It was therefore quite natural that the theory, in the eyes of many, seemed only a loose hypothesis. It is naturally not to be expected that a scientifically educated naturalist should have confidence in a theory based on the observation that the very same species in summer is five times longer than in winter, or that another species in winter is many times greater than in summer, and that without any means of interpreting the manner in which these great variations in body structure take place.

One of the reasons why the study of the variation in plankton organisms has only advanced with the greatest difficulty, is that the

[1] See Wesenberg-Lund, "Von dem Abhängigkeitsverhältniss zwischen dem Bau der Plankton-organismen und dem specifischen Gewicht des Süsswassers," *Biolog. Centralbl.*, vol. xx. pp. 606, 644, 1900; with regard to the viscosity, see Ostwald, "Zur Theorie des Planktons," *Biolog. Centralbl.*, vol. xxii. p. 596, 1902.

conclusions one is obliged to draw are of serious importance in systematic aspects. Everyone who has systematic knowledge of the animal and plant groups dealt with here knows that the specific characters are based especially just on the course of the contour-lines; this applies to the plankton Diatoms, Desmidiaceæ, Ceratium, Rotifers, and Cladocera. As we may now assume that wide limits, just with regard to the course of these contour-lines, can be considered as a *conditio sine qua non* for the occurrence of all these organisms in the pelagic region, we see that these contour-lines in the plankton organisms must be subject to the greatest possible variation. So long as there was not the least conception of this, the study of the plankton led to innumerable species being set up, which have now been reduced to some few: 30 Anuræa species have become 4, about 100 Bosmina species and varieties 2, about 100 Daphnia species and varieties 1 or 2. I have called the old species "races," and objection has been raised against this, perhaps with justice: they should most probably rather be called modifications (or "Phenotypes," Johannsen).

It is very obvious that the naturalists who have dealt with these groups systematically and have created the many species should find it difficult to allow these species to be reduced to definite generations, broods, skin-changes (casts), produced by and adapted to definite outer conditions. Opposition towards the new views is quite natural. When, however, the naturalists of the older school treat the newer views of the species within the plankton community as loose theories which can be dealt with by loose, cursory criticism, whilst at the same time they demand that their views are to be considered as resting on an exact, scientific basis, they must be taken to task. Whatever systematic conception is taken as basis, one thing all should be agreed upon: the notion of species within the lower organisms is always of a distinctly hypothetical nature. The setting up of the numerous species within the plankton organisms was not at all of a less theoretical nature than to reduce them to some few, as at present. In every view of species there is a certain element of the investigator's own individuality. With some the conception of species becomes more and more restricted with years: these are the naturalists who are so fortunate as to be honoured with the title "exact scientists." With others the conception becomes ever wider and wider; it is different at different times and hardly the same within the different countries.[1]

[1] In a work just published ("On *Synchæta fennica*, sp.n.," *Journ. Roy. Micr. Soc.*, 1909, p. 170), Rousselet contests my view of the Synchæta species as seasonal forms. When Rousselet maintains that I have "expressed the opinion" that the Synchæta species "are only seasonal variations of one species," this seems to me a bad starting-point for his criticism, and one which he is scarcely entitled to

Just because the new direction in planktology has to such a high degree given naturalists the opportunity of observing how variable the conception of species within this sphere of work is, it is difficult to understand the demand of the older systematists, that their view of the species must be the only right one.

make. On p. 73 of my plankton work I have expressed myself very carefully. I say: "I still believe it very probable that the 'species' are stages in a variation series; but whether these stages are fixed species in the sense that the variation series consists of a number of temporary species following each other, or whether the transformations are only connected with certain generations and broods of the same species, we do not at present know." I have thus stated expressly that I was unable to determine with regard to the species mentioned whether they were true species or only seasonal forms; and I pointed out also that the material on which my account was based had been procured by others (M. Voigt). Nothing of this is mentioned by Rousselet in his criticism.

Rousselet maintains that the species mentioned cannot be seasonal variations since, according to his statement, they are all found at the same time. This objection is not of any importance, as I have pointed out expressly on p. 251. This will naturally be the case with the seasonal variations at most times of the year. The one form does not disappear on the same day that the other arrives; but whilst the one is decreasing numerically the other is increasing—a fact which will be observed by anyone who follows regularly the forms throughout the year. Stragglers or relicts there must always be of all the numerous forms: I have even found *S. pectinata* and *tremula* side by side in winter. What interests me most in this matter is, has Rousselet at any time found "*S. grandis*" in the months of February and March? With Rousselet's statement that "the periodic and often very sudden disappearance and reappearance of various Rotifers is a well-known fact, and the Synchæta follow the same habits," I am naturally in agreement. But the fundamental matter here, just this "sudden disappearance and reappearance," is not apparently for Rousselet a problem which requires a solution. Now I have endeavoured to give a solution to just this problem by regarding the Synchæta as species, in Rousselet's sense if preferred, but vicarious seasonally, with different times for breaking up the resting-stages and different requirements as to temperature. But Rousselet seems to have quite overlooked this or misunderstood it.

Further evidence that the above-named Synchæta species are in reality species and not seasonal forms is found by Rousselet in this, that "of all plankton Rotifers the Synchæta are the most vigorous swimmers, and quite able to counteract by their cilia any slight tendency to sink that may be due to a decrease in the density and viscosity of the water in summer." To this I would remark, in the first place, that if Rousselet had ever seen a *Ploesoma Hudsoni* swimming he would scarcely have taken the Synchæta to be the most vigorous swimmers; but in the second place, and more especially, whence can Rousselet obtain even the remotest evidence for the view that the wheel-organ of the Synchæta is able to counteract the fluctuations in the density and viscosity? Here, as not so seldom elsewhere, we find the "exact" systematist, without even a shadow of scientific evidence, throwing out random postulates and requiring them to be believed. At the same time he subjects to a superficial and one-sided criticism the views of naturalists who for years have studied the phenomena on which the views rest out in nature itself, under conditions with which the systematist has no acquaintance, and even though these views are put forward in an exceedingly cautious form.

The interpretation of the phenomena has, however, been the object of rather extensive studies, published in 1908. I take the liberty of merely mentioning the principal points in the investigations, and for the rest refer the reader to my main work.

The seasonal variations do not occur, as hitherto believed, *gradually* through even transitional stages; wherever the researches have been made at the right time or where samples have been taken at sufficiently short intervals, it has been proved that the seasonal variations are mainly completed in the *course of a very short time*, about *two to three weeks.* It has been noticed, for example, that there

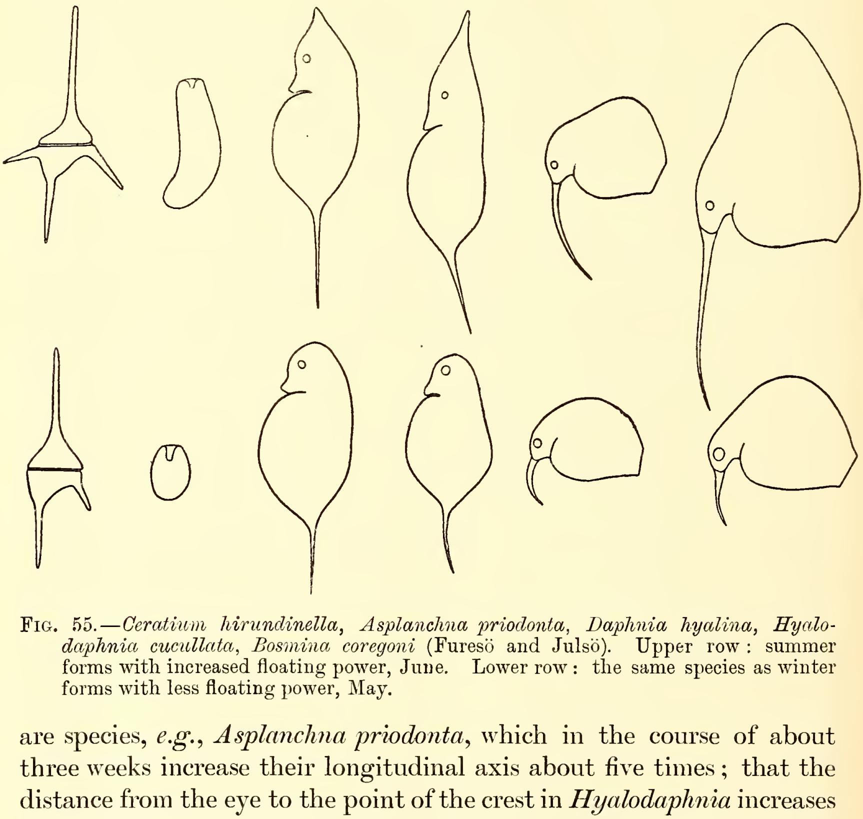

Fig. 55.—*Ceratium hirundinella, Asplanchna priodonta, Daphnia hyalina, Hyalodaphnia cucullata, Bosmina coregoni* (Furesö and Julsö). Upper row: summer forms with increased floating power, June. Lower row: the same species as winter forms with less floating power, May.

are species, *e.g.*, *Asplanchna priodonta*, which in the course of about three weeks increase their longitudinal axis about five times; that the distance from the eye to the point of the crest in *Hyalodaphnia* increases from about 100 μ to 600 μ in the course of three to four weeks (Julsö); and that the flagellum in *Bosmina coregoni* grows from 360 μ to 800 μ (Julsö) in the same time. This means that whilst the joint stock of individuals in the species first had the measurements 100 μ (*Hyalodaphnia*) and 360 μ (*Bosmina coregoni*) (lower row, fig. 55), the great majority of the individuals have got the new sizes about three weeks later (upper row, fig. 55).

The time when the variations are completed is *the same for all* *forms.* At a temperature of 12–14° or 14–16° C., which in the Baltic lake territory mainly occurs at the *end of May and beginning of June*, all seasonal variations are fully formed. Diatoms change their shape of colony, in *Ceratium hirundinella* the fourth horn is developed, or new, narrower, and longer seasonal forms are observed, the longitudinal axis in *Asplanchna* increases in certain localities, the series of variations in *Synchæta* and *Anuræa* arise, the growth in the tip of the crest in *Daphnia* and *Hyalodaphnia* proceeds, the hump in *Bosmina coregoni* grows upwards and the first pair of antennae increase in length; *B. longirostris* as well as many others of the above-named forms decrease in size. At the same time the summer forms appear with their highly developed floating apparatus, viz., *Holopedium*, *Bythotrephes*, *Diaphanosoma*, *Leptodora.* By an abrupt change the whole plankton community has by form variations decreased its rate of sinking and augmented its floating capacity; the rate of sinking for the plankton of June is therefore much less than for the plankton of May.

Towards winter the species has again the external appearance which we are accustomed to regard as normal. Simultaneously the summer forms with their often highly bizarre appearance disappear.

What has happened in these three weeks, in which the whole plankton changes its form and augments its floating capacity? The investigations have now established the following facts.

The demands made by the variations in the outer conditions on the floating power of the species can *generally not be satisfied by the transformation of the single mature individuals.* In Diatoms it is probable that some species, on the rate of sinking increasing, occur in colonies instead of singly, or, if they are generally colony forms, they change the shape of colony through the use of gelatinous masses, which are different qualitatively as well as quantitatively (*Tabellaria*); the individual itself remains, so far as is known, as a rule unchanged. With regard to the Cladocera and Rotifers it may be pointed out, that if the demands become too great, the individual may respond to them by migrating to deeper waters, the temperature of which agrees more with that under which the organisms were hatched and grew up; but doubtless the response most frequently is death. The demands made by the variations in outer conditions are mainly met by the species in such a manner that *the individuals before death produce new broods in which, when hatched, the demands are on essential points already satisfied.* Thus we also find that those individuals which have survived the winter in water layers with high bearing-power, and which are distinguished by relatively plump form, die out in spring. In the brood-pouches of the round-headed winter forms we find broods with pointed heads in the above-named three weeks (figs. 56 and 57). During growth (fig. 58), and before the mature stage is reached, the body form is further remodelled: the result is a long and slender form, more suited to the new demands. After maturity the body is usually fixed in form; it grows further, but retains practically the same proportions as in the last stage before

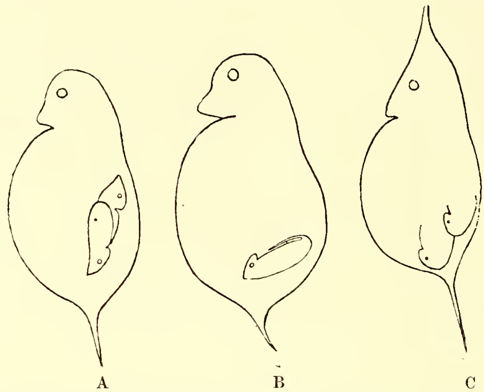

Fig. 56.—Two round-headed spring females (A and B) with pointed-headed young in the brood-pouch; C, a pointed-headed autumn female with round-headed young in brood-pouch.

maturity. This spring generation, which becomes the true bearer of the seasonal variation, is thus on the inception of maturity furnished with a different and greater floating power than the foregoing. The latter has been designated the last generation in the series of winter

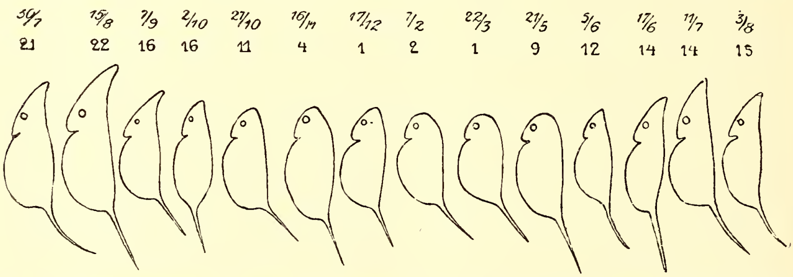

Fig. 57.—*Hyalodaphnia cucullata.* Seasonal variation in the newly hatched young (Furesö). The young are hatched with high crest in summer, but round-headed and without crest in winter. Highly magnified.

generations; the former, the first in the series of summer generations. The direction now taken by the variations increases in all successive generations until the water has attained its highest temperature; but the difference between two successive generations is now never so great as between the two above mentioned, when the temperature of the water is lower (14–16° C.). Sometimes the demands made by the outer conditions on the floating power of the species are so great that they can no longer be met. The research shows that in *Hyalodaphnia* brood- and growth-stages often occur of an extremely high and weak structure, but these are not found again in mature animals: they occur only when the temperature of the water is at its highest,

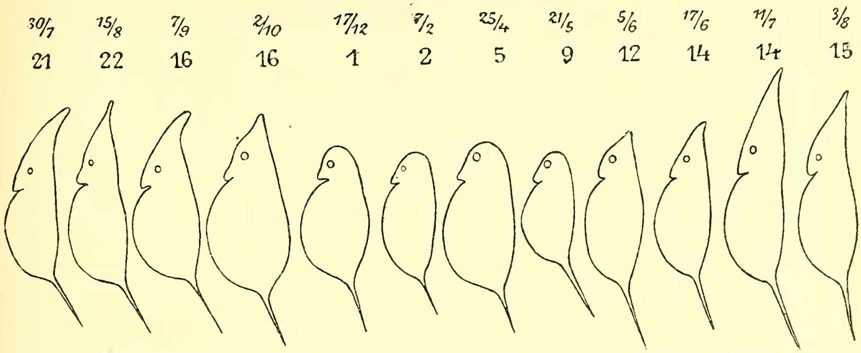

FIG. 58.—*Hyalodaphnia cucullata.* Seasonal variation in the growth-stages (Furesö). During growth the crest in the summer half-year increases so much that it is almost as long as the valves; in the winter half-year the crest does not grow at all.

and their lifetime seems always very short. The view which I have taken of the phenomenon is that the claims of the outer conditions laid at this time on the species are so great that each individual may well meet them but has been forced so near the limits of the variability of the species that the individual pays for its extreme by sterility. *The most extreme variations produced by outer conditions can thus not be inherited.* (Fig. 59.)

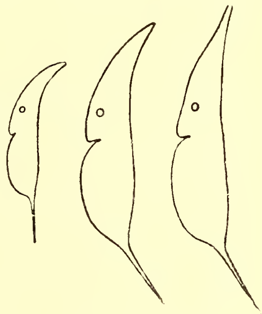

FIG. 59.—*Hyalodaphnia cucullata.* Individuals which the demands for increased floating power have forced beyond the limits of elasticity of the species. They do not attain to the mature stage, and in any case do not produce eggs.

In the beginning of autumn, the great increase in the parts of the body which have to counteract the rate of sinking ceases during growth. Somewhat later, generations are produced in which, on hatching, the crest is shorter and does not increase during growth. Towards the winter the species has again the exterior which we are accustomed to regard as normal.

In what manner does the individual transform itself? We must restrict ourselves to the following remark. There is reason for believing that the outer conditions which produce the seasonal variations principally assert themselves, or at any rate make their influence felt, just at the *period succeeding the new moult.* If this holds good, then the seasonal variations, *i.e.* the faculty of the animal for adapting itself to the variations in outer conditions, are dependent on the intensity with which the moults proceed. In this the explanation might perhaps be sought as to the phenomenon which, of all those connected with seasonal variations, has always appeared to me the most puzzling. It is easily understood why the organisms in spring, when the rate of sinking rises, transform their bodies so that the floating power becomes greater; but in all the earlier researches I did not see for a long time how to explain why these floating apparatus when once formed are again drawn in towards winter. Their formation in spring is necessary, and may well be thought of as brought about through selection, but I was unable to see any necessity for their being drawn in in autumn. If it were possible to show, however, that the body is only transformed during and soon after the moults, and that the frequency of the latter is dependent on outer conditions—first and foremost on temperature, so that they proceed most rapidly and frequently at high and increasing temperatures, more slowly and rarely at lower and decreasing—the explanation would also be found here of the phenomenon that the Cladocera are transformed in spring but in autumn cease transforming. Thus the return to the common race would not occur because the organisms no more "needed" floating apparatus and therefore drew them in, but for the very simple reason that the organisms when the moulting processes ceased were practically not able to transform themselves.

The very peculiar fact that the seasonal variations do not proceed gradually but by a sudden change, which occurs in all plankton at the same period (May, June), when the temperature is at 12–14° C., and is completed in the course of two to three weeks, *makes us understand that the seasonal variations really may be of the greatest significance for the plankton organisms.*

2. *Local Variation.*—We are now able to understand how the seasonal variations take place, and how the plankton organisms of the fresh water are able, by means of variations in the body form, to follow the variations in the buoyancy power of the fresh water.

The investigations on which my results have been based were not carried out in a single lake, but in many, so that I was able not only to follow the seasonal variations in many lakes, but also to study the local variation of the plankton organisms.

These studies gave the following, very peculiar, main results. Although the seasonal variations, which have everywhere the same object, proceed on parallel lines in different localities, considerable differences may nevertheless assert themselves both with respect to the amount of variation in each locality and with respect to details in the manner in which the organism meets the demands for variation in floating power. I shall here restrict myself to the remark, that there are species of which *every lake may practically be said to have its own race.* These racial characters seem invariable from year to year; this is especially the case with some Daphnids (*D. hyalina*, *Bosmina coregoni*). Thorough investigations have further given the following results.

It has been proved for Rotifers as well as for Cladocera that, how-

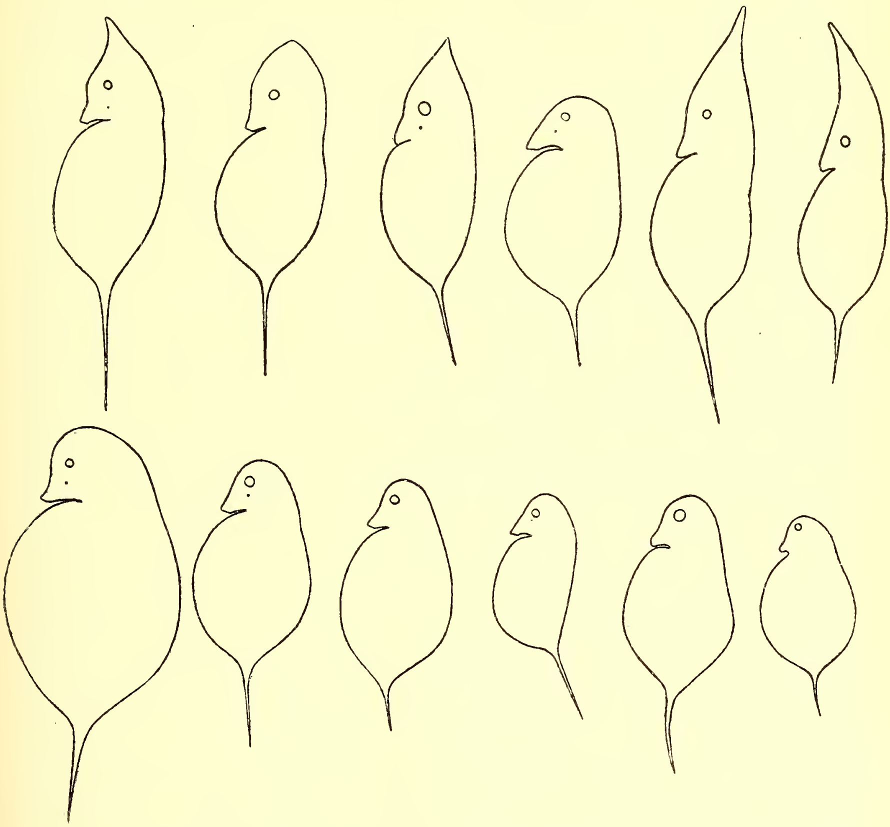

FIG. 60.—*Daphnia hyalina.* Upper row: summer races from different Danish lakes. Lower row: winter races from the same lakes. The summer races differ very much from each other; the winter races are almost of the same appearance.

ever far the local variation is carried, *these races, wherever the research has been made, fall back in winter upon one and the same common race, which in each species is invariably the same in all localities investigated* (fig. 60). On the seasonal variations beginning in spring, the local races proceed from this common form. The fact that this common winter form has been shown to be the homogeneous element from which all summer races proceed and to which all return, is to my mind of no small importance. When first I got a clear understanding of this phenomenon, it struck me as very peculiar. In *D. hyalina* it was extremely striking to see this very same race in the course of only two to three weeks (May, June) everywhere changing into slender forms with pointed heads, the external appearance of which, moreover, was in every lake quite different. But still more remarkable was it to see how all these various summer races, when autumn came, slowly dropped their racial characters and in winter ended in the same clumsy, round-headed form common to all lakes. What means have we now to understand the sudden appearance of the very many summer races in spring, and to understand the appearance of the common winter race?

The occurrence of the numerous local races is favoured by the *frequent monogonic reproduction* in plankton organisms (asexual formation of auxospores in Diatoms; not constant and regular conjugation, but mainly reproduction by partition in *Ceratium*; conspicuous tendency to acycly in *Rotifera* and *Cladocera*). Directions of variation once begun can therefore continue undisturbed; no crossing from conjugation, and consequent disturbance and interruption in the directions of variation commenced, takes place. Resting-stages, resting-cysts, resting-eggs, etc., which as a rule are also the means of distribution of the species, are lost with the falling out of digonic reproduction. In this way the races are separated; each locality becomes an exclusive world to them; they do not receive any impulses from without, and the racial characters can be preserved over great areas.

The main causes of the disappearance of the sexual reproduction of the plankton organisms may be sought for in the fact that the production of the resting-stages, and especially their thick, chitinous skeletons, made so great claims on the mother-organisms that their organisation came into conflict with the demands made by the outer conditions; *i.e.*, in many localities the resting-stages made the mother-organisms too heavy. The result would be then, that the individuals forming resting-stages would sink down into deeper layers and perish. We are therefore able to understand the disappearance of resting-stages through selection.

How are we further able to understand that all the numerous summer races fall back into one and the same winter race? To understand this phenomenon we must look beyond the boundaries of the small country in which these investigations have been carried out, and go back to other periods in the life-history of our globe.

On comparing my own with the investigations of others in arctic alpine lakes, I was able to show in 1905, and later in 1906, that *seasonal variations are restricted to the low-lying lakes of the temperate zone, and are absent from the arctic, alpine, and North European lakes* in which the temperature did not for some time remain over about 12–16° C., and in which great annual fluctuations of temperature did not occur (fig. 61). The investigations in alpine lakes in Switzerland and Austria have given quite the same result, whereas the seasonal variations in the lowland lakes of the same countries take place quite as in the Baltic lakes. Just as the seasonal variations in our lakes do not take place at temperatures above 12–16° C., they are not traceable in lakes which never reach this temperature. Where the claims for increased floating power are not pressed, those structures by which it is augmented will not be formed by the organism.

It is still more peculiar that not only the seasonal variations but also the local variations almost totally disappear under arctic con-

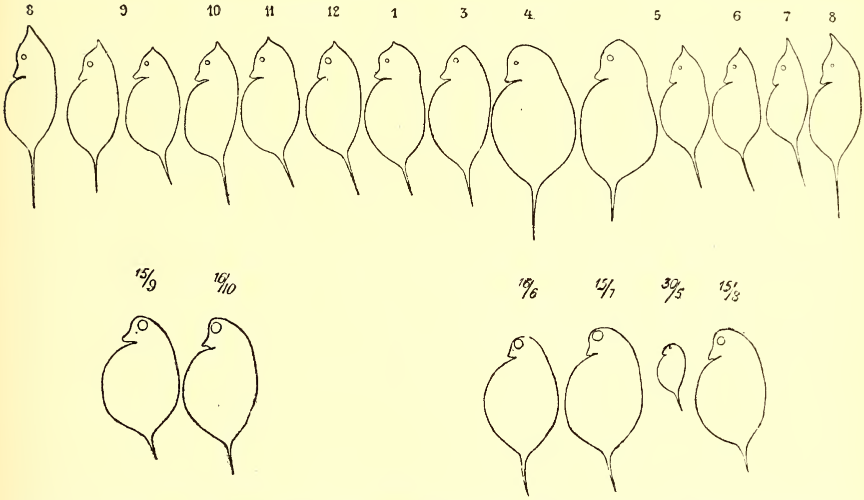

FIG. 61.—*Daphnia hyalina* in Esromsö, Denmark (above), and in Myvatn, Iceland (lower). In Esromsö we have a conspicuous seasonal variation, in Myvatn this is absent. In Esromsö, *Daphnia hyalina* overwinters as a free-swimming organism, in Myvatn only in ephippia.

ditions. On an area so small as Zealand, *D. hyalina* has in almost every lake a special, well-defined race. If, on the other hand, we compare examples from Greenland, Iceland, Sarek in Sweden, and from the northern parts of Finland it will be seen that the race characters have almost disappeared. *All these forms may without any difficulty be referred to one or two types easily distinguishable from the summer forms of southern countries*[1] (fig. 62). Now it has further been

[1] The peculiar phenomenon that the local variation is lost in the high north is in full accordance with the fact that the species of Daphnids with which we have to do in the arctic region, like the plankton organisms in large lakes, have preserved the digonic propagation. Everywhere where investigations have been made it has been shown that resting-eggs are formed; sexual propagation, which prevents race-formation, is still retained; and the resting-stages, the means of distribution, are carried by means of rivers and wind from lake to lake.

shown that this very same common race, which inhabits the fresh waters of the Arctic and which is nearly related to the race from the high alpine lakes in Switzerland, *is the very same race which in winter inhabits the Baltic fresh-water lakes and from which the numerous local summer races proceed* (fig. 62, upper row, compared with fig. 60, lower row).

We have now obtained the material from which it is possible to

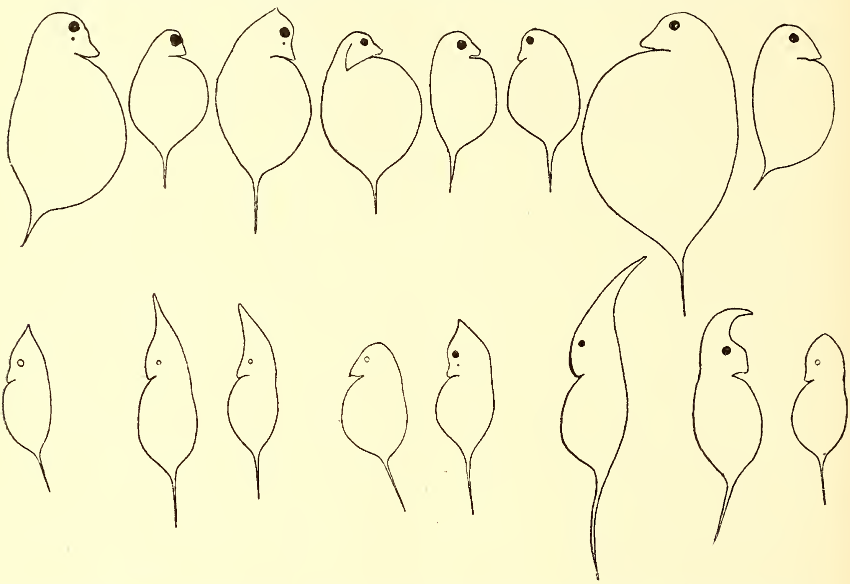

Fig. 62.—*Daphnia hyalina.* Upper row: summer forms from lakes which rarely or never reach a temperature of about 12–16° C. (Achensee, Brehm; Sarek, Ekman; Thingvallavatn, Wesenberg-Lund; Myvatn, Wesenberg-Lund; Kola, Levander; Mjösen, Huitfeldt-Kaas). Lower row: summer forms from lakes which annually reach more than 12–16° C. (Viborgsö, Wesenberg-Lund; Esromsö, Wesenberg-Lund; Tjustrupsö, Wesenberg-Lund; Västergotland, Lilljeborg; Pomerania, Seligo; Haldsö, Wesenberg-Lund). The local variation is very inconspicuous in the cold lakes, but very prominent in the warm lakes.

understand why all the local summer races are in our lakes condensed into one single race in the winter time.

Influence of the Ice Age on the Fresh-water Plankton

During the tundra period the northern part of Central Europe was covered with innumerable lakes and pools which remained after

The colonies of the single lake thus escape isolation, and race-formation cannot occur. The main cause why a species is able as plankton organism only to form its resting-stage in the Arctic is probably that the arctic lakes have not the high summer temperatures. Thus, also, the rate of sinking is never so great in the northern lakes, and the mother-animals are therefore able to form and carry the resting-stages, which undoubtedly increase the weight of the animals.

the ice had retired. All these fresh waters have probably been populated by the same, at all seasons almost invariable, common races which even nowadays predominate in those parts of the globe where an Ice Age still prevails, or are close to the boundaries of the ice. As the temperature rose the lakes became differentiated, and lake-types with different biological conditions came into existence; the race primarily common to all lakes was split up into various small races. Through selection, those mother-animals which produced resting-eggs disappeared; the loss of resting-stages was followed by isolation of the colonies and fixation of the races. *The result was a very distinct local variation.* With the improvement in the climatic conditions the necessity for increased powers of floating was modified in proportion as the specific gravity and viscosity changed. As the temperature rose and the bearing power of the fresh water in the summer diminished, the plankton organisms had only one of two things to do: either to accommodate themselves to the claims for increased floating power, or perish. By increasing and developing such processes as counteracted the increasing rate of sinking, *the seasonal variations arose. The deeper basis of the causal connection between the variations in the plankton organisms and those in the bearing power of fresh water is therefore to be sought for in the amelioration of the climatic conditions which began after the Glacial Age*, the consequent higher temperature of the water, and at the same time the continually increasing rate of sinking. As a concomitant of the amelioration of the conditions may also be emphasised better nourishment. My opinion is partly based on the fact that all seasonal and local variation is absent, or at any rate is not conspicuous, in the arctic region, partly on the fact that all southern local races fall back upon the same winter race, which of all races is that which is nearest related to the present arctic race of the species concerned. *This winter race is therefore to be regarded as a reminiscence preserved from periods remote in the development of our races of the present day.*

Just as in the course of a year we see those modifications brought about which have been developed in the course of the thousands of years which separate us from the remote periods when our waters were inhabited only by the poorly equipped arctic races of the present day, so we can probably observe quite the same development when we study, lake by lake, locality by locality, the conditions in a country which reaches the temperate zone in the south and the region of eternal snow in the north.

According to this view, the local variations of the plankton organisms may be said to be arranged in *series of forms* (*Formenreihen*, Sarasin, Plate, Neumayer, etc.). The causes of the origin of these series of forms are different. With regard to the plankton organisms, I believe that they are connected with the more varied and transitory changes in the surroundings caused by the melting of the ice and the subsequent improvement in the climatic conditions after the Ice Age. As all the changes in the shape of the plankton organisms tend to reduce the rate of sinking, all being mutually connected and parallel with the rising temperature and the decreasing viscosity, vertically through time as well as horizontally from north to south, I conclude that for the plankton organisms it is a *conditio sine qua non* to follow the variations in the supporting power of the fresh water, which again are dependent upon temperature and concentration. As we now further know that the temperature, though with fluctuations, has risen from the Glacial Age to the present day, I would also conclude that the rising temperature subsequent to the improvement in climate after the Glacial Age was the direct external stimulant responsible for the occurrence of these series of forms.

As the difference between summer and winter temperatures and the consequent yearly variation in the supporting power of the water continually increased over more extensive areas, the species were constantly forced nearer to the limits of their range of variation on endeavouring to adapt themselves to the decreasing supporting power. The sexual periods in the pelagic colonies of the large lakes were at the same time more and more on the decline, and consequently local races arose. Through seasonal variations these races adapted themselves to the buoyancy conditions of the locality, and through selection the single links during wanderings arranged themselves in series of forms from north to south.

I have long held the view that the way in which variations in the outer conditions contribute to the occurrence of morphological series of variations is, that a biological separation has preceded the morphological division. Behind the morphological variations are the *biological*; both are but rarely printed on paper or preserved in museums, but he who lives much in nature has them before his eyes every day. Outer conditions first influence the mode of life of the organisms; the modifications in the latter through increased or decreased use of certain functions or structural characters then cause those differences to appear by means of which the different stages in the morphological chains can be distinguished. The division of the species brought about by variations in outer conditions often remains in the biological stage. Outer conditions separate a species into a number of groups of individuals differing biologically, but not to be distinguished morphologically. Examples of this must be sought for at present mainly among the lowest organisms, yeast and bacteria; but there is no doubt that even if the number of such biological species known within the higher many-celled organisms is but small, the reason lies far more in the great difficulty of these researches than that such cases are rare. Examples are known, however, of insects which, transferred from Europe to America, completely change their habits; viz. the bean beetle in Europe (*Haltica rufipes*), which in America attacks fruit-trees; *Anthrenus scrophulariæ*, which in Europe feeds on blossoming fruit-trees, but in America lives in houses and causes great damage to carpets and furniture. Further species occur, *e.g.*, among gall-flies, morphologically not to be distinguished, but biologically very different, and producing galls of great diversity in appearance (*Cynips caput-medusæ*, *C. calicis*). Also, the attacks of the Kea upon the New Zealand sheep may be mentioned.

From these biologically separated groups of individuals the morphological form series may arise, the specific biological functions produced by external circumstances causing variation in outer shape. The reason why such cases are so rare is the great difficulty of following the development or of finding any fixed stages in the chains of forms which might show the development. As examples may be noted the biological division of species of parasitic insects with regard to the different animals on which they live and their consequent variation in colour (Sajó, 1904, p. 372); the nut-cracker (*Caryocatactes nucifraga*), which in Siberia lives on the seeds in the cones of the Siberian cedars, in Europe mainly on nuts, acorns, etc.; in Siberia its beak is longer and narrower, in Europe stronger (Weismann, 1902, p. 378); here we possibly have to deal with a horizontal series of forms derived from a morphological series, which again has had its starting-point in biologically separated groups.

It hardly requires to be pointed out that the single links in a chain of forms are naturally not arranged either horizontally (through space) or vertically (through time) with such great regularity that the forms with the best buoyancy apparatus are invariably found farther south or in higher earth-strata than those with less developed apparatus. During the melting period of the ice there have been times when the temperature fell after rising; and in many tracts of land where the climatic conditions might ordinarily be considered as temperate, localities occur with temperatures many degrees lower than the normal for the latitude of those parts. Far to the north, on the other hand, there are places, for example on the southern faces of mountains, where the temperatures are much higher than the normal for the region (G. Andersson, 1902, p. 1; 1906, p. 45). At such periods and localities there will naturally be some irregularities in the chain of forms. At times and places, possibly with higher temperatures, forms will appear with a greater development of the apparatus for floating than those in recent geological strata and farther south, just as the reverse may also occur. The evidence of such breaks in a chain of forms is not in the least in opposition to the view set forth here regarding the old collective species as chains of forms.

Though I believe, as above stated, that these series of forms originate in the extreme north, this does not at all mean that the arctic forms with which the series begin owe their origin to the Glacial Age; of this nothing is decidedly known, and I consider this opinion quite erroneous.

In recent years different scientists have tried to explain many facts connected with remarkable distribution or peculiarities relating to the biology of the plankton organisms as caused by the Ice Age. Some authors have advanced the idea that the whole fresh-water plankton should be regarded as a society which has immigrated into the fresh-water lakes from the Arctic Sea during the Ice Age. In my opinion, this idea is quite erroneous. *The home of the fresh-water plankton must mainly be sought for in the littoral and bottom regions of the lakes*, and most of the fresh-water plankton organisms may be designated as bottom and littoral forms which have adapted themselves more or less to pelagic life and made themselves independent of bottom and bank, where the great majority still pass a shorter or longer period of their lives. Reasons for this view I have set down in chap. xiii. of my *Plankton Investigations*. With regard to the influence of the Glacial Age on the fresh-water plankton I share the view that we have been too hasty in making the Glacial Age responsible for the occurrence of forms at localities outside the true centre of distribution of the species, and for remarkable biological facts relating to the biology of the plankton organisms. Without going into details, I shall here merely summarise my opinions as follows. *In the life-history of the fresh-water plankton the Glacial Age has only been a phase of transient importance*: it has influenced the history of this community as well as of all other communities, but less than most. The individuals of the species which lived within the territories overtaken during the Glacial Period have suffered from this, but not the other individuals. This period lasted long enough to leave its mark on some characteristics of the species influenced by it. It affected their nutrition, their reproduction, and their shape. At the end of the Glacial Period races of these very old species, even then distributed over the whole earth, occurred in the northern part of the temperate zone, and owing to the Glacial Period they had become adapted to arctic or subarctic climatic conditions. The special characters impressed upon them by the Ice Period still persist, as is shown by the present races returning in winter upon the old races of this period (the present arctic races) and by their predilection for low temperatures.

The new conditions which the temperate zone after the end of the Glacial Age offered its organisms have, on the other hand, also acted long enough to leave their mark on structure and mode of life. Such marks are the variation, local as well as seasonal, both of which are nothing but the efforts of the organisms to adapt themselves to the development of more favourable biological conditions consequent upon the milder climatic conditions. The differentiation in the outer conditions involved differentiation in structure.

How have these extensive researches on the variation in the Northern and Central European fresh-water plankton influenced our conception of the species? We must in this paper be content to deal mainly with the Cladocera and leave the remainder to the future.

I have here come to the point which is the goal of so many other comprehensive studies. I confess openly that I have held conflicting views at different times, but I believe that the result which I have arrived at lately is for me permanent. However honest and sincere one's researches may be, and however much one tries to be impartial, in such domains one is, in my opinion, only able to see what one is "born" to see, *i.e.* the combination of claims and conditions which is the reflection of one's self. I consider it highly probable that if other observers with other natural gifts had procured the material shown here and had now to say the final word, they would express it differently from what I should. Man cannot, on the whole, get beyond what he thinks is the nearest truth.

According to my view, the researches clearly show the almost incredible elasticity of the plankton organisms and their adaptability to variations in outer conditions. For many extremely different organisms the research has more or less distinctly shown that a transformation takes place in the shape of the organisms, which is uniform in its final results and everywhere parallel with certain fixed local and seasonal variations in outer conditions. This harmony between the variations in outer conditions and those in the shape of the plankton organisms is, *in my opinion*, so conspicuous that I do not doubt but that the latter are the outcome of the former. It seems to me that but few researches have been able to display so clearly the influence of outer conditions on the organisms; but even with regard to this point the mere subjective view cannot, as above noted, be excluded. According to my opinion, the salient point is that the research has proved the causal connection between the shape or form of the plankton organisms and certain regular variations in outer conditions. Which of the two really "strikes the first blow" in the mutual play between organism and outer conditions, whether the organism is forced or permits itself to be forced, is in my opinion a contest of words, and provisionally may be left alone. Through this research I believe I have had my eyes opened to the influence which outer conditions may directly have on the transformation of the organism; a somewhat secondary part is indeed also played by selection.

We may return now to the question—How are we to consider all these single links in the chains of forms, all these local variations? Do they belong to one and the same species, or may they simply be regarded as "Standortsmodificationen" which, as soon as the individuals are taken back to the localities where they originally lived, return to the original form of the local race from which they sprung? In other words, are they comparable with the form series of Celebes snails described by the brothers Sarassin, or have we to do with chains of forms of geographically separated species fixed by inheritance, corresponding to those demonstrated by Wettstein in *Euphrasia* (1896) and *Gentiana* (1896, p. 307; 1900, p. 305), and after him by Sterneck in *Alectorolophus* (1901, p. 1)?

On this matter we can at present form no definite judgment. It is for the rest obvious that researches on the formation of species in plankton organisms, as they penetrate more deeply into diverse domains, will yield quite different results. What is wanted here is experiment: until we have such before us each one may retain his own subjective opinion.

As for me, I believe that a great part of the local variations are to be regarded as in fact constant forms (*petits espèces* of the botanist), which may, however, be connected with forms not constant, but which under other conditions either return to or develop into one another. I therefore bring all the forms under single large collective species: *D. longispina*, *B. coregoni*, etc. If it should be objected that this standpoint is not quite consistent, I would answer that it is the nearest approach to nature, where all is in a fluctuating condition, in constant process of development. The sharp boundaries are man's work: any greater precision in description than the subject permits oversteps the aim, and should, in my opinion, be avoided. This investigation has therefore tended more to delete the boundaries between forms than to make them more fixed.

Summary.—We have now endeavoured to give a brief review of the investigations of recent years on the variation of plankton organisms. That this variation is advantageous for the plankton organisms, and one of the means by which the cosmopolitanism of the fresh-water community is rendered possible, is in my opinion very probable.

Owing to their form-changing power, the organisms are able to adapt themselves to the variations in the rate of sinking, and consequently to shorten the resting-periods more than normally. This causes, as a rule, an increase in the number of individuals in the locality concerned, and is thus favourable to the species. It may be supposed that the supporting power of fresh water, as mentioned above, is different in different latitudes, and the possibility is not excluded that it diminishes from north to south. I am inclined to believe this, because the variability of the species, as mentioned above, is not equally great in the arctic and high alpine lakes and is slight in the North European. On the other hand, it is greatest in the Baltic lakes, *i.e.* the variability of the species is smallest where the variations in the supporting power are smallest, and greatest where these are greatest. All these variations tend to augment the cross-section resistance, and thus to diminish the rate of sinking of the organisms. We may therefore say that the cross-section resistance of the organisms increases from north to south.

Further, it has been shown with regard to many of the most well-marked plankton organisms, that a decrease in volume takes place in the direction from north to south; it therefore seems as if the organisms also undergo a relative increase in superficial area consequent upon a decrease in volume. Both phenomena agree very well with the fact that both the increase in cross-section resistance and the increase in superficial area owing to diminution in volume are in each locality most prominent in summer. Local as well as seasonal variations tend mainly to increase the form-resistance on the rise of temperature, viz. on the rate of sinking probably on the whole increasing.

In order to disprove or confirm these views, knowledge of the appearance and mode of life of the plankton in tropical fresh-water lakes is necessary. We know nothing of the reproduction there, nor of the variations, either local or seasonal. The little to be gathered from the literature seems to suggest that adaptations to the extremely high summer temperatures, in so far as they come under the conception of change in shape, consist less in an increase of the cross-section resistance through extensive formation of floating apparatus, and more in an increase of the superficial area due to a decrease in volume. With this increase in superficial area there is in the tropical fresh-water plankton an apparently distinct tendency towards making the surface rough by means of numerous closely placed roughnesses, reticulations, etc. It is a remarkable fact that no organism has yet been observed in tropical fresh-water lakes which through extensive formation of floating apparatus is specially adapted to water with high temperatures and slight supporting powers: the Hyalodaphniæ in Victoria Nyanza seem quite similar to our own. The most conspicuous structure I know of is the very large mucrones in Bosminæ from the river Amazon (Stingelin, 1904c, Tab. 20, f. 6).

I am inclined to believe that the plankton organisms, under the continually increasing demands of outer conditions upon them from north to south to diminish the rate of sinking, have down to a certain zone, which may perhaps be placed in the Mediterranean area, mainly responded to these demands by an increase in the cross-section resistance. As the species during this process of adaptation approached too near to their limits of variation and the demands for diminishing the rate of sinking still continued, they took to the method of increase in superficial area through decrease in volume; in this way possibly some racial characters disappeared. If this should prove correct, an interesting difference appears between the tropical fresh-water plankton and the tropical marine plankton, which is characterised by its immense formation of spines, processes, etc. The former has met the demand for diminishing the rate of sinking by increase in superficial area through decrease in volume; the latter, by an increase in cross-section resistance by means of an extensive formation of spines, processes, skin-folds, gelatinous membranes, etc.

In all structures tending to increase the cross-section resistance, *i.e.* the temporal variations, I am inclined to see the means by which the organisms try to answer the annual variations in the supporting power of the fresh water in a given locality, and in the increase in superficial area from diminution of volume the means by which the organisms during the distribution in the direction from north to south try to counteract the increasing rate of sinking in the same direction.

It would be in full accordance with this theory if further investigations should prove, on the one hand, that the seasonal variations are only small in the tropics, because there, as well as in the arctic regions, the annual range of temperature in the plankton region of larger lakes is relatively slight; and, on the other hand, that the superficial area, through diminution of volume and rich development of asperities, is greatest, because the supporting power of fresh water, though rather constant throughout the whole year, is less than in any other part of the globe.

These suppositions are only put forward as working theories for future explorers of the tropical fresh-water lakes.

PART III.—MAIN PROBLEMS OF FUTURE LIMNOLOGICAL INVESTIGATIONS

Sir John Murray has further done me the honour to ask me to indicate here what kind of work I consider most needed at present in the science of limnology. I wish to call special attention to two points.

As already mentioned, we lack almost all knowledge of the tropical lakes. No thorough investigations have been carried out with regard to their temperatures, and the other physical and chemical conditions are quite unknown. With regard to the life of the littoral flora and fauna we have only cursory and rather casual descriptions and observations; the abyssal fauna we only know for some of the large African lakes, and as regards the plankton our knowledge is very unsatisfactory (Apstein, *Lake Colombo*, 1907, p. 201). I am of opinion that it is in the tropical lakes that we shall find the proofs of the correctness of many of the above-named theories. Shall we find seasonal variations in the plankton organisms of the tropical lakes? Is the local variation very conspicuous? Is the average size of the different plankton organisms smaller than in the temperate lakes? Is the propagation chiefly digonic or monogonic? What part is played by the resting-stages in the life of the species? What is the periodicity of the plankton organisms? Do they make vertical wanderings? Is the relation of the tropical fresh-water plankton to that of the ocean closer than that between the lake plankton and oceanic plankton of the temperate zone? Is v. Martens' supposition, "Die Aehnlichkeit der gesammten Süsswasserfauna mit der gesammten Meerfauna nimmt vom Pol gegen den Aequator zu," indisputable and of the same validity for all associations in the fresh-water lakes?

In my opinion, *a thorough exploration of one of the great tropical lakes is one of the most desirable objects for the promotion of limnology.* Attention is drawn involuntarily to the great African lakes, where Moore's investigations have given such valuable scientific results, and where the German investigations and those of the Messrs West have in so high a degree increased our knowledge of the fresh-water flora. That this investigation will be both very expensive and, owing to the climatic conditions, probably much more dangerous than many oceanic and polar explorations is unfortunately beyond doubt.

When preparing my work on the plankton for the press I looked over the whole literature relating to fresh-water plankton, and was often astonished at the very great differences in the interpretation of the biology even of the most common plankton organisms. From the foregoing we have seen that the plankton, both with regard to their morphology and their biology, follow different lines in different latitudes. The great differences in the interpretation of the biology and morphology by different investigators are therefore quite natural. What we in planktology as well as in every other part of limnology most of all need is *simultaneous, coherent investigations in different latitudes from north to south.* We need such investigations with regard to temperature. This has for a long time been clear to limnologists (John Murray, Forel, Pettersson, 1902); and a first paper on simultaneous temperature observations in Lakes Enare, Mjösen, Wetter, Ladoga, Loch Katrine, Lake of Geneva, has been published; still, temperature observations in the tropical lakes are wanting, and those for the arctic lakes are unsatisfactory. The investigations made are, as a first attempt, of great interest, but they by no means exclude the necessity for further observations. If such simultaneous temperature investigations could be combined with limnographical and chemical researches at different latitudes, we should in a couple of years be able to get wide fundamental views which all researches in these vast fields of labour at this moment lack.

In the foregoing we have dealt with the cosmopolitanism of the fresh-water organisms, especially that of the plankton. We can point out many species of plankton organisms which are just as much at home in the dark, ice-cold arctic lakes as in the hot tropical lakes; *e.g.*, amongst Rotifers we know about ten species, amongst Crustacea *Daphnia hyalina*, species of *Bosmina*, among Diatoms the *Melosiras.* It is just with regard to these species that great differences in the views of their morphology and biology prevail. What is wanted here is regular fortnightly investigations carried out simultaneously in different latitudes. From these we should get a clearer understanding of the above-mentioned different uses of digonic and monogonic reproduction in different latitudes; we should get a much more thorough knowledge of the form-series of the plankton organisms, and undoubtedly learn many more than those we now know (Diatoms, Desmids, Calanidæ, Rotifera); from these investigations much material for the great questions with regard to the origin of species might be gained.

As is well known, the different North and Central European States have joined in the great scientific co-operation, the international exploration of the sea. A corresponding international limnological exploration needs neither such great apparatus nor the enormous sums which the exploration of the sea demands. All that is necessary is to have for a period of one or two years a few scientifically educated men placed at six or seven localities arranged in almost the same longitude from the north to the equator. We should use one or two places of observation in the arctic regions (Greenland and Lake Enare), in Scotland, and in the great Swedish lakes, in the Baltic lakes, in a high alpine lake, in the Lake of Geneva, and in the great African lakes. If a similar series of observations could be carried out in America, and if a station could be founded on the Baikal Lake, these would be of great use. To carry out this plan, neither great congresses nor many committee members or great sums granted by Governments are necessary, but only a very few scientists agreeing in the main points and with relatively modest funds, which in most cases will not exceed what scientific societies or bodies interested in this kind of exploration at present expend. It must be remembered that such observations in Scotland, in the great Swedish lakes, in the Baltic lakes, and in the Lake of Geneva, as well as in many of the American lakes, may be connected with investigations already being carried out, and by investigators who at these places have already studied the very same phenomena. In all these localities the investigations will be relatively cheap: neither money nor the right men would be difficult to get. The great difficulties arise only in the case of the arctic and tropical lakes, and, as far as I can see, especially the latter. Here it is probably necessary to restrict the demands, and to remember that it is not altogether necessary that the scientists should live during the whole year at the locality; they might leave the plankton collecting and temperature observations to men who during the stay had been trained for that purpose. The material collected should be given into the hands of a committee, who should determine its further elaboration. Sooner or later this plan will undoubtedly be carried out. Whether the present is the right moment, I do not know; but I do not see why it should not be.

Whilst pointing out what, in my opinion, is most needed to promote limnology, I wish at the same time to indicate briefly the lines which, in the present position of the science, may be regarded as already worked out. When the plankton investigations began, very many small papers relating to the pelagic fauna or flora of fresh water appeared. Many of these papers were the result of a single excursion, and the plants and animals were cursorily determined. Papers of this kind are now indeed rare, but they have by no means quite disappeared. It must be strongly emphasised that all papers of this kind, if they are only the result of a single excursion and the collection only contains common forms, are of exceedingly little scientific use. This holds good especially for the material obtained from the temperate zone. For example, no scientist who has made an excursion in a stretch of woodland thinks of communicating to the scientific world that he has found violets and wild flowers; but just as unnecessary is it to communicate that one of the thousands of Baltic lakes is populated with *D. hyalina*, *Polyarthra platyptera*, and other cosmopolitan species. Publications of this kind should no longer be printed in scientific periodicals.

During the last ten years we have obtained from different countries a number of *lake descriptions*; they belong almost all to the temperate zone, principally to the Baltic or Swiss lakes. We find in these papers a pot-pourri of very many different branches of natural science: physics, chemistry, geology, meteorology, zoology, botany, all treated and finished off in one or two hundred pages. The starting-point for these publications is that a lake is a sharply limited piece of nature with its own laws to which the organisms are compelled to accommodate their organisation. The great model is Forel's excellent monograph, *Le Léman.* All these papers deal with the regular annual variation in temperature, the transparency of the water, a little in regard to environment, a list of organisms—never complete and only thoroughly carried out for those groups which most interested the author. In the biological parts we find casual remarks, but really the only remarks of scientific value. All the papers finish with a chapter giving the results of the investigations, the peculiarities of the physico-chemical conditions combined with the characteristics of the organic life, intended to give us a clear understanding of this one lake as different from other lakes. These chapters are almost identical in all the papers.

In my opinion, the whole of the above tendency in limnology has perhaps been correct and useful during its infancy; now, I think it must be regarded as a stage in evolution which we have outgrown. If a lake has to be thoroughly explored, it is of course necessary to have a *preliminary* idea of the lake, its physico-chemical conditions, and its biology, but only rarely is it necessary to publish this material. It is just such preliminary explorations that the above papers represent, and beyond them the investigations of the lake concerned only seldom extend.

When this preliminary exploration has been done, the more thoroughly scientific work should begin. We will, for example, suppose that the littoral region of the lake is to be explored. If so, there is no sense in studying all the organisms simultaneously. The expert limnologist will quickly find out some few species which ought specially to be investigated; from the observations on the morphology, biology, etc., of these, carried out every fortnight for a year, questions will arise which can only be answered through investigations of the surrounding medium. This study will therefore involve others, and will naturally lead to the study of the whole littoral region, its organisms and conditions of life.

At present all such studies can in a very high degree be furthered by means of *fresh-water biological stations.* If we remember all the excellent investigations on the biology of fresh-water organisms (Daphnids, Apus, Trematodes, Cestodes, water-insects, Volvox, many phanerogams) which have been carried out for a long time, long before any one had even the slightest idea of what a biological laboratory was, and further that such laboratories have existed for about twenty years, we might really expect that, under the much better conditions for the study of the fresh-water organisms, knowledge of their biology might have been more advanced in these last twenty years. This, however, is by no means the case. The laboratories have scarcely increased our knowledge with regard to the life of higher plants, water-insects, and almost the whole organic life of the littoral zone. Even in regard to the plankton it is strange to note how few really new facts with regard to the individual plankton, animal or plant, the biological laboratories have brought to light. These principally deal with the biology of plankton diatoms and plankton Myxophyceæ. The main reason is, that many of the laboratories are bound by obligations to the fishery, which in my opinion neither promotes the fishery nor the limnology; but also, partly, that the studies as mentioned above have been carried out on far too wide a base. It must be admitted that this method, when the biological stations began their work, was tempting and perhaps also necessary. Nowadays, it must be demanded from the laboratories, *that regular study of the single organism on the spot where it lives and where it grows is in future one of their chief tasks.* Situated in nature itself, the laboratories have the great advantage of never wanting material, as also that the organisms can be studied at the very place to which they primarily belong. It is in nature itself that the investigations of the fresh-water laboratories should be carried out, *and the investigators must learn to transfer the experimental work and the biological observations from the aquaria to nature itself.* By means of *marked* animals and plants, studied at regular short intervals the whole year round, this is very well possible. In my opinion, it is from such studies that these laboratories will be able to increase our knowledge of the biology of the fresh-water fauna and flora in a very high degree. Studies of this kind have hitherto been carried on only with regard to the plankton—in general for the whole plankton community at once, and only very rarely for a single plankton organism.

When similar investigations on the same or other organisms are carried on in other latitudes, we will gradually get the biology of the species elucidated, not only at the different seasons of the year, but also at the different localities. Then, by and by, the material will be brought together on the basis of which we shall be able to build up what in the infancy of the science of limnology could of course only vainly be attempted.

If the investigations are carried out as now sketched, it will be understood that a very great deal of the time of the investigators will be spent on excursions. From the explorations in nature, questions arise which can only be solved either by histological or by detailed anatomical investigations, or, if they belong to the vast field of heredity, by cultivation and experiment carried on for a long time under special conditions. For all these studies our investigators will hardly find sufficient time; nor do they in reality belong to the main work of the fresh-water laboratories. Hitherto they have always been accomplished in the anatomical and physiological institutes in the University cities, and there I think they ought to remain. What is needed is a much more thorough co-operation between the fresh-water laboratories and the University institutions. This co-operation is lacking at this moment, partly because the fresh-water laboratories have misunderstood their main tasks and tried to study as if they themselves were University institutes, which they usually are unable to do, and which originally was by no means their aim. I am also inclined to think that the University institutes are a little contemptuous of the studies carried on by the laboratories in nature. If this originates from the common impression of the investigations hitherto, this is intelligible; if it originates from the supposition that the work accomplished by these laboratories is only to be regarded as pioneer work, thus implying inferiority in its scientific aspect as compared with all contributions to the solution of the great problems of life made by the University institutes, this is quite a misunderstanding. In our days only very few can carry out an investigation in all branches which lead to a solution of the question concerned: he who digs the gold out of the earth is not he who coins it, but the gold-digger is not on that account made the subject of reproach.

Before the new step above outlined in the development of the fresh-water laboratories can be accomplished, some time will certainly elapse. The laboratories themselves must educate the scientists who are able to carry out these studies. University education, as it now is, usually diverts the student from living nature: the young naturalists produced by the Universities have a much more intimate knowledge of nature preserved in alcohol and formalin. When they leave the Universities, stained and embedded nature is much more likely to occupy their attention and arouse the spirit of inquiry than living nature. It is the study of the living organisms in nature itself which must be regarded as an independent phase in nature study. In my opinion, it is just this study we need, and the fresh-water and marine laboratories should make it their first aim to bring it into existence.

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THE SCOTTISH LAKES IN RELATION TO THE GEOLOGICAL FEATURES OF THE COUNTRY

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Before discussing the question of the probable origin of the rock-basins in Scotland, a brief account will be given of the geological structure of the country and of the development of its topographical features prior to the Ice Age. Thereafter the successive stages in the glaciation of the region will be described and their relation to the distribution of Scottish lakes will be discussed.

Geological Structure of Scotland

LEWISIAN GNEISS

In the North-West Highlands the oldest rocks are typically developed. Consisting of Lewisian gneisses and schists, they form a belt along the western seaboard of Sutherland and Ross from Cape Wrath to Loch Torridon, and appear in Rona, the northern part of Raasay, Coll, Tiree, and the Outer Hebrides. The detailed examination of the region between Cape Wrath and the island of Raasay by the Geological Survey points to the conclusion that the Lewisian Gneiss may be resolved into (1) a fundamental complex, composed mainly of gneisses that have affinities with plutonic igneous products, and to a limited extent of crystalline schists which may be regarded as of sedimentary origin; (2) a great series of igneous rocks intrusive in the Fundamental Complex in the form of dykes and sills.

The rock groups of the Fundamental Complex that have affinities with plutonic igneous products have a more or less definite geographical distribution; the first district extending from Cape Wrath to Loch Laxford, the second from near Scourie to beyond Lochinver, and the third from Gruinard Bay to the island of Raasay. In the central area (Scourie to Lochinver) pyroxene gneisses and ultrabasic rocks are specially developed, while granular hornblende rocks and biotite gneisses are characteristic of the northern and southern tracts. Sometimes these rocks appear like ordinary eruptive masses, sometimes with crude mineral banding, and yet again with well-defined foliation.

The schists of sedimentary origin have a limited development north of Loch Maree and near Gairloch. The prominent members of the series are quartz-schists, mica-schists, graphitic-schists, limestones, and dolomites, with tremolite, garnet, and epidote. They are there associated with a massive sill of epidiorite and hornblende-schist.

After the development of the early mineral banding of the gneisses, the Fundamental Complex was pierced by a remarkable series of igneous intrusions in the form of dykes and sills; comprising ultrabasic rocks (peridotite), basic rocks (dolerite and epidiorite), and acid rocks (granite and pegmatite). The evidence in the field points to the conclusion that the ultrabasic rocks cut the basic, and that the granite dykes and sills were intruded into the gneisses after the eruption of the basic dykes.

After the intrusion of these various igneous materials, the whole region was subjected to terrestrial stresses which affected the gneisses of the Fundamental Complex and the dykes which traverse them. These lines of movement traverse the Lewisian plateau in various directions, producing planes of disruption, molecular rearrangement of the minerals, and the development of foliation in the gneiss and dykes. In these zones of shearing the coarse pyroxenic gneisses are replaced by granulitic biotite and hornblende gneisses, and the basic dykes merge into bands of hornblende-schist.

After the cessation of these terrestrial movements, and before the deposition of the sediments that now form the overlying Torridon Sandstone, the Lewisian Gneiss underwent prolonged denudation. In the north-west of Sutherland, between Durness and Loch Laxford, the surface of these ancient rocks was worn down to a comparatively level plane; but farther south, in Assynt and onwards to Loch Torridon in Ross-shire, it was carved into a series of deep narrow valleys with mountains rising to a height of about 2000 feet.

TORRIDONIAN

Throughout the North-West Highlands the Torridon Sandstone rests on the various members of the Lewisian Gneiss with a violent unconformability, which must represent a vast lapse of time. This formation is divisible into three groups: a lower, composed of epidotic grits and conglomerates, dark and grey shales with calcareous bands, red sandstones and grits; a middle, consisting of a great succession of false-bedded grits and sandstones; an upper, comprising chocolate-coloured sandstones, micaceous flags, dark shales and calcareous bands. The total thickness of this great pile of sedimentary deposits must be not less than 10,000 feet.

The Torridonian strata can be traced from the precipitous headlands of Cape Wrath to Applecross, where they form pyramidal mountains of great height. They reappear to the east of this undisturbed area, among the displaced masses affected by the post-Cambrian movements, notably in Assynt, in the area extending from Kishorn to Loch Alsh, in Sleat, and in Rum.

CAMBRIAN

The Torridon Sandstone is overlain unconformably by an important series of fossiliferous strata comprising quartzites, fucoid shales, *Salterella* grit, dolomites, and limestones. The age of these sediments has been definitely fixed by the discovery in the fucoid beds of trilobites belonging to the *Olenellus* zone—the lowest division of the Cambrian system. In the neighbourhood of Durness these dolomites and limestones reach their greatest development, and are there divisible into zones, some of which have yielded cephalopods, gasteropods, lamellibranchs, brachiopods, and sponges. It seems probable that the greater part of the Durness limestone represents the middle and upper divisions of the Cambrian system, and possibly the base of the Lower Silurian rocks of North America.

An interesting series of plutonic igneous rocks, ranging in composition from quartz-syenite to nepheline-syenite and borolanite, appear in the Cambrian strata of Assynt, which are accompanied by numerous sills and dykes comprising felsites, porphyrites, and vogesites. These intrusions are later than all the Cambrian rocks of the region, and older than the post-Cambrian movements.

The fossiliferous Cambrian strata are followed eastwards, and in certain sections are visibly overlain by a great development of crystalline schists, which Murchison regarded as conformable with the underlying sediments. But this theory of natural sequence was not accepted by Professor Nicol, who contended that the superposition of the Eastern schists on the Cambrian rocks was due to earth-movements. The detailed examination of the region by Bonney, Lapworth, Callaway, and the Geological Survey has confirmed the accuracy of Nicol's main conclusions. For, by means of lateral compression or earth-creep the strata have been thrown into a series of inverted folds which culminate in reversed faults or thrusts, the effect of which is to bring lower over higher beds. This reduplication of the strata by inverted folds and reversed faults is an accompaniment of the great horizontal displacements by which thick slices of Lewisian Gneiss, Torridon Sandstone, Cambrian rocks, and the Eastern Schists have been driven westwards for miles. In other words, the rocks in that region behaved like brittle, rigid bodies which snapped across, were piled up, and thrust westwards in successive slices.

These great displacements were accompanied by differential movement of some of the rocks, which resulted in the development of new structures. These features are especially developed at or near the Moine thrust-plane, which is the most easterly of the powerful lines of disruption. There we find that the Lewisian Gneiss, Torridon Sandstone, and Cambrian quartzite are sheared and rolled out, presenting new divisional planes parallel to that of the Moine thrust.

Regarding the age of these post-Cambrian movements, it is obvious that they must be later than the Cambrian dolomites and limestones, and older than the Old Red Sandstone; for the basal conglomerates of the latter rest unconformably on the Eastern Schists, and contain pebbles of quartzite, dolomite, and limestone derived from the Cambrian rocks of the North-West Highlands.

METAMORPHIC ROCKS EAST OF THE MOINE THRUST-PLANE

East of the Moine thrust-plane, whose outcrop runs from the eastern shore of Loch Eireboll S.S.E. to Loch Alsh, we enter the wide domain of the metamorphic rocks of the Highlands, which extend to the Highland border. Two prominent types of crystalline schists (Moine Series of the Geological Survey) have been traced over wide areas in the counties of Sutherland, Ross, Inverness, and across the Great Glen to the Grampians. These consist of granulitic quartzose schists and muscovite biotite schists which appear to be of sedimentary origin. They are associated with recognisable masses of Lewisian Gneiss, which present many of the structures so characteristic of the fundamental rocks along the western seaboard of Sutherland and Ross. From the relations which these rock-groups bear to each other in the field, the inference has been drawn that the Moine schists represent a sedimentary series resting unconformably on the Lewisian Gneiss, the latter being brought to the surface along inverted folds and exposed by denudation. In the east of Sutherland, foliated and massive granites appear which are intrusive in the Moine schists and produce contact metamorphism.

In the Eastern Highland belt, ranging from the counties of Banff and Aberdeen through Perthshire to Argyll, the Moine series is replaced by metamorphic rocks, undoubtedly of sedimentary origin, which have been termed the Dalradian series by Sir A. Geikie. These have been divided into certain lithological groups which have been traced more or less continuously from Banff and Aberdeen to Kintyre. There seems to be an apparent order of superposition in these subdivisions as the observer passes northwards from the Highland border to the crest of the Grampians, which may or may not be the original sequence of deposition. In Perthshire the groups are met with in apparent descending order, as given below :—

12. Blair Atholl limestone and leaden schist.
11. Quartzite (Schichallion).
10. Black schist with thin limestone.
9. Calcareous sericite schist (Ben Lawers).
8. Garnetiferous mica-schist (Pitlochry).
7. Loch Tay limestone.
6. Garnetiferous mica-schist.
5. Schistose epidotic grits (Green Beds).
4. Ben Ledi grits and schists.
3. Aberfoyle slates.
2. Leny grits.
1. Cherts, black shales, and grits of the Highland border.

It is worthy of note that contemporaneous volcanic rocks (lavas, tuffs, and agglomerates) are associated with the sediments of groups 1, 10, and 11 ; for the structures of the pillow lavas are still well preserved in certain areas where they have escaped deformation, notably in north Glen Sannox, Arran, and near Tayvallich, south of the Crinan Canal, in Argyllshire. Moreover, before planes of schistosity were developed in these Dalradian strata, they were pierced by intrusive sheets of basic igneous rock (gabbro and epidiorite) and acid material (granite), both of which shared in the movements that affected these schists.

The age of these Dalradian sediments is still unsolved. In the memoir on "The Silurian Rocks of Scotland" the Geological Survey correlated the cherts and pillow lavas of the Highland border (group 1) with the Arenig cherts and volcanic rocks of the Southern Uplands ; but though radiolaria have been detected in the Aberfoyle cherts, the evidence cannot be regarded as sufficient to prove this correlation. Indeed, recent researches in Anglesey and the Lleyn peninsula in North Wales suggest that they may belong to pre-Arenig, if not pre-Cambrian, time. The presence of annelid tubes in the quartzites of Islay, Jura, and of the adjoining mainland is not sufficient to link these rocks with the Cambrian quartzites of the North-West Highlands ; for, notwithstanding such evidence, they might well be of older date. In this connection, however, it is instructive to remember that in the south-west of Islay there is a mass of gneiss of Lewisian type similar to that in the North-West Highlands, overlain unconformably by sedimentary strata, which have been correlated with the lower and middle divisions of the Torridon Sandstone. Unfortunately the sequence ends here, as both the gneiss and overlying sediments are separated by a line of disruption or thrust-plane from the quartzites and fucoid beds in the eastern part of the island.

Much uncertainty prevails regarding the original sequence of deposition of the Dalradian sediments, the tectonics of the various rock groups and their relations to the Moine series along the chain of the Grampians. Various theories have been advanced to solve these problems, but each of them leaves difficulties unsolved. It has been contended that there is an ascending sequence from the Leny grits and Aberfoyle slates (groups 2 and 3) to the quartzite of Schichallion (group 11), the latter being the highest member of the series. But whatever may be the ultimate solution of these questions, it is clear that the crystalline schists of the Moine series and the Dalradian rock groups were affected by a common system of folds, the strike of the axial planes trending north-east and south-west. Great recumbent folds with an amplitude of several miles, accompanied by lines of disruption (thrust-planes), were produced, which are a striking feature in the Glen Nevis and Glencoe areas. Another result has been the development of a fan-shaped arrangement of the folding along an axis extending from Ben Lawers in Perthshire to Loch Awe in Argyllshire.

The crystalline schists of the Eastern Highlands were pierced by a later series of plutonic rocks comprising granites and diorites which now form large areas along the Grampian chain. Certain of these are undoubtedly of Lower Old Red Sandstone age, but the presence of granite boulders in the basal conglomerates of that formation in Argyllshire shows that some of the non-foliated granites in the Highlands must be of older date.

From this brief outline it appears that the metamorphic rocks of the Highlands, between the Moine thrust-plane and the boundary fault extending from Stonehaven to the Firth of Clyde, include rock groups belonging to different geological periods, though linked together by a common system of folding. A broad mountain chain of metamorphic strata may have existed in the Central and Eastern Highlands in Cambrian and Silurian time. Some, however, contend that there is no conclusive evidence of the existence of such a chain till the period of elevation that preceded the close of Silurian time.

SILURIAN

The geological structure of the Silurian tableland of the Southern Uplands is extremely complicated, due partly to the non-fossiliferous character of many of the strata, partly to the inversion of the rocks over wide areas, and partly to the variation in the types of sedimentation, ranging from oceanic to shallow water and shore conditions. But by means of the vertical distribution of the graptolites Professor Lapworth has demonstrated the true order of succession of the strata. The evidence obtained in the course of the detailed examination of the region points to continuous sedimentation from Arenig to

Ludlow and Downtonian time, except in the north-west area, where local unconformabilities occur.

The strata are arranged in a series of flexures, the axes of which run in a north-east and south-west direction parallel to the longer axis of the tableland. Frequently the folds are inverted, both limbs dipping in the same direction, and hence mere superposition is of no value in determining the order of succession of the sediments. Moreover, the types of sedimentation of the Llandeilo, Caradoc, and Llandovery strata to be found in the Central Moffat region differ in a marked degree from those that occur along the northern margin of the tableland, and particularly in the neighbourhood of Girvan.

One prominent rock group—the lowest in the sequence—preserves, with rare exceptions, its uniform lithological characters throughout the uplands. Consisting of cherts and mudstones, the former containing radiolaria and the latter hingeless brachiopods, they belong partly to Upper Arenig and partly to Lower Llandeilo time. The cherts, which have been formed from radiolarian deposits, and the mudstones indicate an oceanic phase of sedimentation. Their horizon is clearly defined, for they are overlain by black shales (Glenkiln) with graptolites of Upper Llandeilo age, and they rest on volcanic rocks, containing, in the Girvan area, cherty mudstones and graptolitic shales yielding Middle Arenig graptolites. The greatest development of Arenig volcanic rocks occurs near Ballantrae in Ayrshire, where they consist of diabase and diabase-porphyrite lavas, agglomerates, and tuffs, pierced by various plutonic masses, including serpentine, gabbro, dolerite, and granite. They reappear, however, on numerous anticlines along the northern margin of the tableland and elsewhere throughout the uplands, where they are overlain by the radiolarian cherts.

The subdivisions of the Moffat series overlying the radiolarian cherts and Arenig volcanic rocks established by Professor Lapworth in the central portion of the tableland, viz. Glenkiln shales (Upper Llandeilo), Hartfell shales (Caradoc), and Birkhill shales (Llandovery), imply conditions of deposition near the verge of sedimentation; for they consist of black shales, cherty bands, and mudstones, with rare intercalations of coarser sediment. The total thickness of these divisions of the Silurian system in the Moffat region does not exceed 300 feet, but when traced north-westwards to the margin of the tableland they are represented in the Girvan area by upwards of 5000 feet of strata. The gradual increase in thickness of these divisions in this direction is due to the fact that the land from which the sediment was derived lay to the north.

The members of the Moffat series appear at the surface in a series of sharp anticlines amid a broad development of younger sediments of Tarannon age, comprising conglomerates, grits, greywackes, flags, and shales, which are repeated by folding over a belt of ground twenty miles across in the central part of the tableland. Along the northern margin of this belt the Birkhill shales (Llandovery) are replaced by coarser sediments, and are represented by grits, greywackes, and shales with thin carbonaceous seams yielding dwarfed representations of Lower Birkhill graptolites.

The northern belt of the uplands, which stretches from the northern slope of the Lammermuir Hills south-westwards by Leadhills and Sanquhar to Loch Ryan and Portpatrick, is composed of Arenig, Llandeilo, and Caradoc strata, which rise from underneath the younger Tarannon sediments of the central region. In the northern tract these divisions of the system show lateral variations of the strata. For example, the Hartfell black shales (Lower Caradoc) undergo modification, and graptolites appear in thin black seams interleaved in flaggy shales or in dark sandy shales. The barren mudstones (Upper Caradoc) of the Central Moffat region are represented in the northern belt by grey micaceous shales (Lowther shales), greywackes, and grits, with lenticular masses of limestone, which, at Wrae and Glencotho, are associated with volcanic rocks. In like manner the Glenkiln shales lose their normal characters, and their graptolites are found in thin dark seams in sandy bands interbedded with greywackes and shales.

In the Girvan region, as shown by Professor Lapworth, these lateral modifications of the strata are more strongly marked, for the Moffat series is there represented by a vast thickness of conglomerates, grits, greywackes, flagstones, shales, and limestones. To the north of the Stinchar valley, in the Girvan and Ballantrae region, the Llandeilo and Caradoc rocks rest unconformably on an eroded platform of Arenig volcanic rocks, but south of the Stinchar valley this unconformability disappears.

Along the southern margin of the uplands the Tarannon rocks of the central belt pass conformably upwards into Wenlock and Ludlow strata, which yield fossils characteristic of these subdivisions.

North of the Silurian tableland, and within the area occupied by the Old Red Sandstone, near Lesmahagow and in the Pentland Hills, various inliers of Upper Silurian rocks are exposed, ranging from Wenlock to Downtonian time. The distinctive palæontological feature of these inliers is the remarkable fish fauna found in the Ludlow and Downtonian strata. The latter division consists of red and yellow sandstones and conglomerates with shales and mudstones, forming passage beds between the underlying Ludlow rocks and the overlying Old Red Sandstone, like the Downton rocks of Shropshire. The discovery of ostracods, phyllocarid crustaceans, eurypterids, and fishes—an assemblage of organic remains identical in some respects with that of the underlying Ludlow rocks—led to a change in the classification of these strata by the Geological Survey. Though formerly grouped with the Old Red Sandstone, the Downtonian strata are now regarded as forming the highest subdivision of the Silurian system in the south of Scotland.

The Silurian strata are pierced by various igneous masses, comprising granite, quartz-diorite, and hyperite, together with numerous dykes of porphyrite, diorite, and mica-trap. From the relations which they bear to the Silurian strata and to the Upper Old Red Sandstone, it is evident that they are of Lower Old Red Sandstone age. Other igneous intrusions of later date traverse the tableland, to which reference will be made in the sequel.

Towards the close of Downtonian time the Silurian strata were elevated and subjected to prolonged denudation; for, both in Ayrshire and the Pentland Hills, the basal conglomerates of the Lower Old Red Sandstone, containing greywacke pebbles derived from the old tableland, rest unconformably on the folded and eroded edges of the Silurian rocks. In Lanarkshire this unconformability has not been detected, as there seems to be a passage in that district from the one formation to the other. At that period also the crystalline schists of the Highlands must have formed a prominent land barrier towards the north before the deposition of the Lower Old Red Sandstone sediments.

THE OLD RED SANDSTONE

The series of deposits belonging to the Old Red Sandstone are generally supposed to have been laid down in inland lakes, owing to their distinctive lithological characters and the nature of their organic remains. Instead of a profusion of marine forms we find abundant remains of land plants, ganoid fishes whose living representatives are now found in rivers and lakes, eurypterids, bivalve crustaceans, and myriapods. But, whether lacustrine or marine, it is clear that the whole series presents different lithological characters from those of the underlying Silurian and overlying Carboniferous rocks.

The sediments of the Old Red Sandstone may be grouped in three great divisions—the lower, middle, and upper—a classification based partly on the fish remains and partly on the land plants found so abundantly on certain horizons.

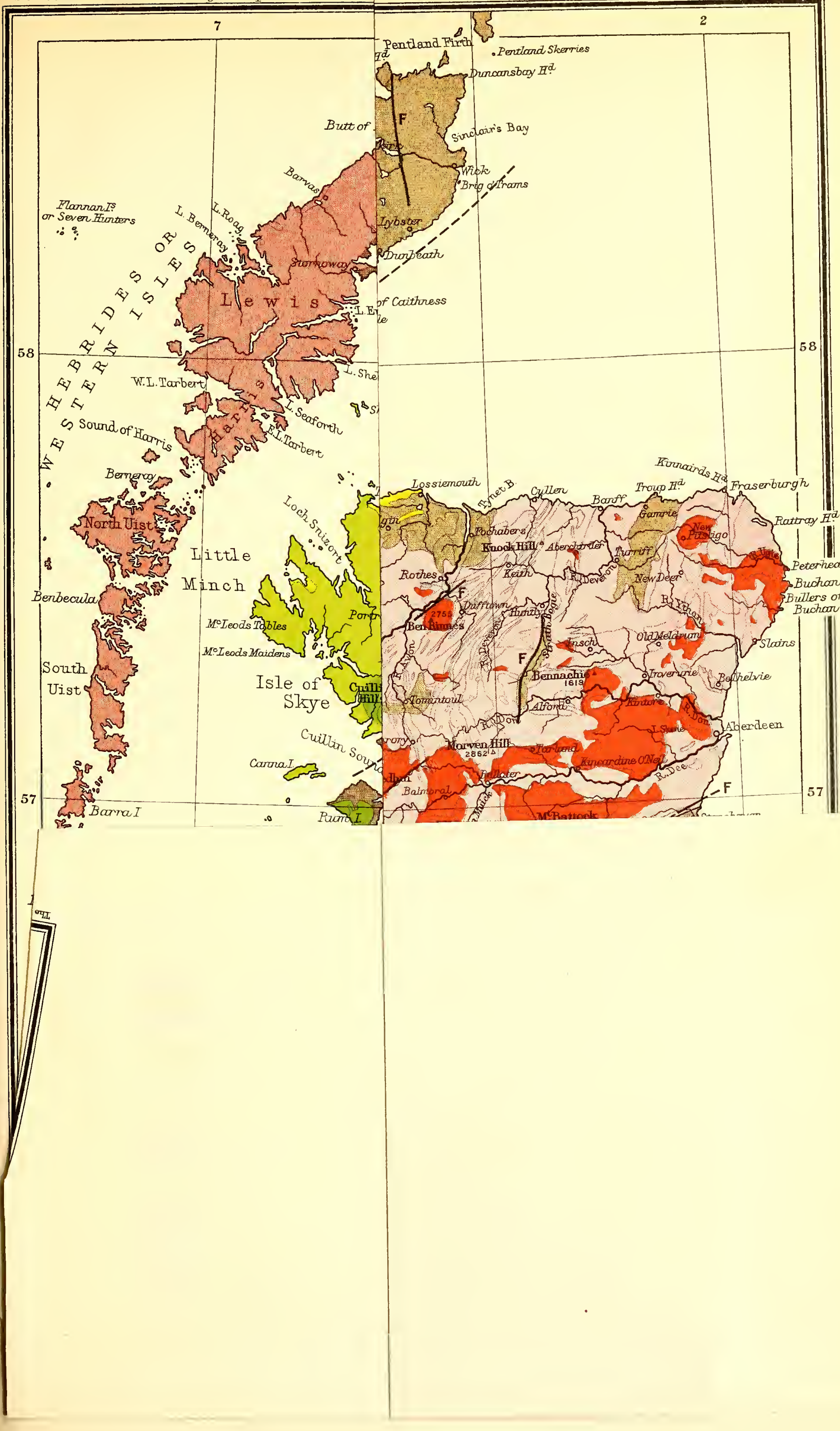
The representatives of the lower division occur to the south of the Grampian chain, and in the Central Lowlands form parallel belts—the one extending from the coast of Kincardineshire and Forfarshire to the mouth of Loch Lomond and the Firth of Clyde, the other from the Pentland Hills south-west to Ayrshire. The centre of this basin is occupied by Carboniferous and Triassic strata.

The deposits of the lower division may be arranged in three groups: (1) a lower, consisting of conglomerates, sandstones, and flags with no volcanic rocks; (2) a middle, composed almost wholly of lavas, tuffs, and agglomerates; (3) an upper, consisting of conglomerates, sandstones, flags, and mudstones. The members of the upper group are splendidly developed in the centre of a great trough extending from Stonehaven by the Braes of Doune to near Drymen—a distance of 100 miles; while the lavas and ashes of the middle group rise from underneath these and form a prominent arch in the Sidlaws and Ochils. The members of the lower group are exposed on the coast at Stonehaven, where, at their northern limit, they are truncated by a powerful fault which brings them into conjunction with the metamorphic rocks of the Highlands. As already indicated, this great dislocation stretches from the Kincardineshire coast to the Firth of Clyde, and through part of its course brings different members of this formation against each other. On the north side of the fault, between Crieff and Cortachy, there is a development of coarse trappean conglomerates with thin beds of lava occupying the horizon of the volcanic series and resting unconformably on the metamorphic rocks, while the underlying beds are absent or sparingly represented. It is apparent from this overlapping of the strata that there must have been a gradual depression of the Highland barrier, and that as the waters of the lake crept northwards the crystalline schists of the Highlands were buried under the accumulating sediments of the higher groups.

The foregoing subdivisions are conspicuously developed in the belt that borders the northern margin of the Southern Uplands. In this case also the Lower Old Red Sandstone is bounded by a great fracture extending from Midlothian to the Firth of Clyde, whereby this formation has slipped downwards against the Silurian tableland to the south. In the Pentland Hills the volcanic series, comprising andesites, rhyolites, and tuffs, forms conspicuous features in the landscape and is traceable at intervals along the belt south-westwards into Ayrshire. Beyond the Silurian tableland, in the Cheviots, these volcanic rocks are well developed, and they form a broad plateau in Lorne, Argyllshire, where they are associated with sediments which have yielded fish-remains of Lower Old Red Sandstone age. They likewise appear in the Glencoe region and on the crest of Ben Nevis.

A striking feature of this period is the extent and variety of the plutonic intrusions (granite, diorite) in the Highlands and Southern Uplands, to which reference has already been made.

In the great northern area, where the middle or Orcadian series of the Moray Firth, Caithness, Orkney, and Shetland appears, there is a marked divergence in the character of the strata and the fish fauna from that on the south side of the Grampians. Murchison clearly


Pentland Firth
Pentland Skerries
Duncansbay Hd
Butt of
Sinclair's Bay
Wick
Brig o' Trams
Lybster
Dunbeath
of Caithness
Barvas
L. Roag
L. Bernera
Stornoway
Lewis
Flannan Is
or Seven Hunters
WESTERN ISLES OR HEBRIDES
W.L. Tarbert
L. Seaforth
E.L. Tarbert
Harris
Sound of Harris
Berneray
North Uist
Little Minch
Benbecula
South Uist
Barra I
Loch Snizort
McLeods Tables
McLeods Maidens
Isle of Skye
Cuillin Sound
Canna I.
Rum I.
Lossiemouth
Cullen
Banff
Troup Hd
Kinnairds Hd
Fraserburgh
Rattray Hd
Gamrie
New Pitsligo
Fochabers
Knock Hill
Aberchirder
Turriff
Rothes
Keith
R. Deveron
New Deer
Peterhead
Buchan Ness
Bullers of Buchan
Dufftown
Huntly
Ben Rinnes
2755
Old Meldrum
R. Ythan
Slains
Insch
Bennachie
1619
Inverurie
Belhelvie
Tomintoul
Alford
Kintore
R. Don
Aberdeen
Morven Hill
2862
Tarland
Kincardine O'Neil
R. Dee
Ballater
Balmoral
Mt Battock
F
7
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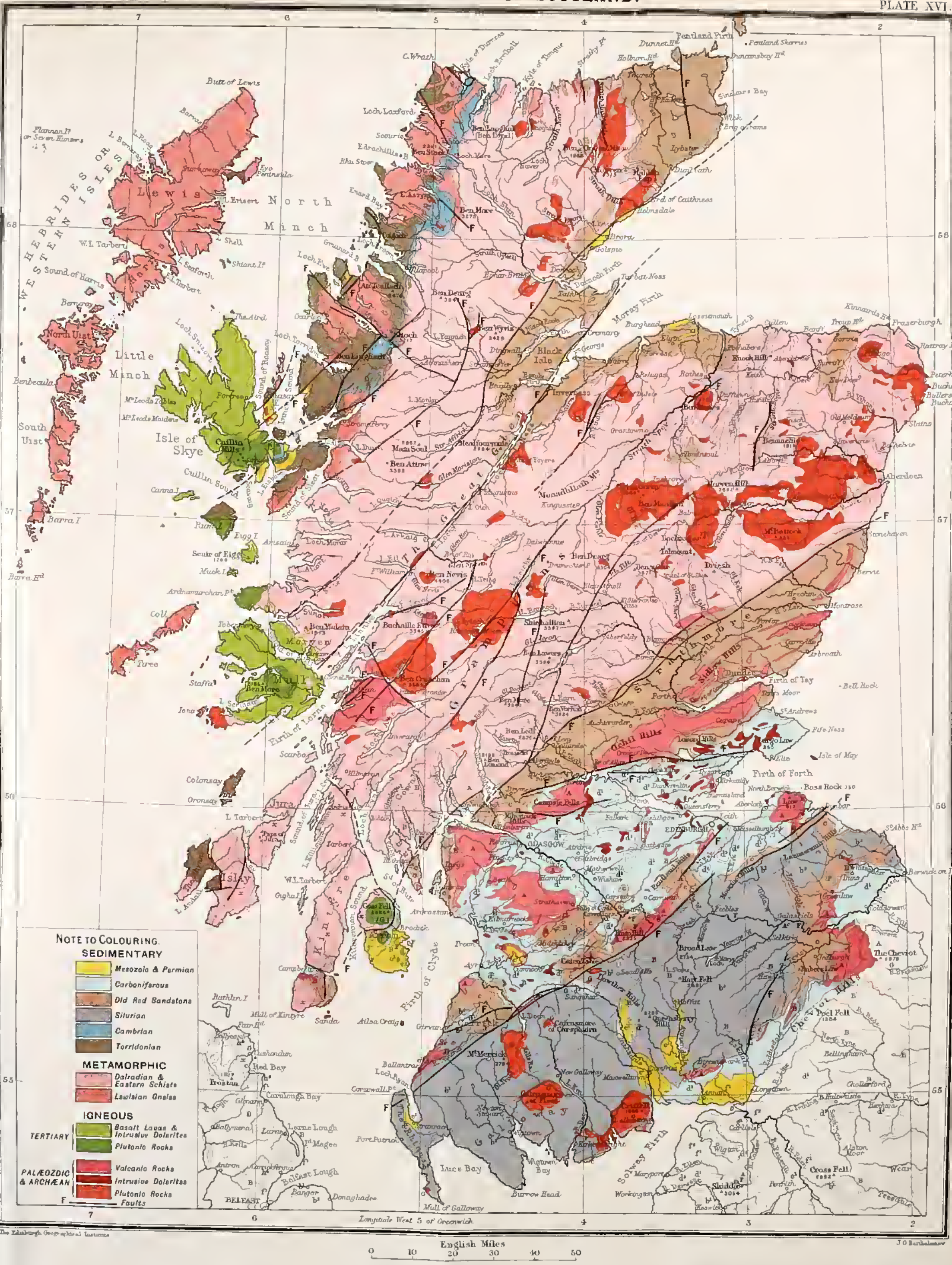
58
57

GEOLOGICAL MAP OF SCOTLAND.



recognised this divergence as represented in Caithness, and referred the flagstone series to the middle division of the Old Red Sandstone—a view which has been strengthened by the researches of Dr Traquair in recent years. In that county, conglomerates and sandstones occur at the base, and graduate upwards into grey and blue bituminous flagstones charged with fish-remains, and succeeded by the sandstones and flags of John o' Groats. On the other hand, Sir A. Geikie contends that the Orcadian series north of the Grampians are the equivalents in time of the Lower Old Red deposits south of that chain. He further holds that the admitted palæontological distinctions between the two areas are probably not greater than the contrast between the ichthyic faunas of adjacent but disconnected water basins at the present time.

The Upper Old Red Sandstone everywhere rests unconformably on the older rocks, but graduates upwards into the Carboniferous formation. The nature of this unconformability clearly shows that the members of the lower division, including the volcanic rocks, were elevated, folded, and subjected to extensive denudation before the deposition of the Upper Old Red strata. In places valleys or hollows were excavated in the Silurian tableland during this period of erosion.

The strata consist of conglomerates, sandstones, marls, and cornstones, from which a characteristic assemblage of fish-remains has been obtained. North of the Grampians they appear in the coastal belt of Elgin and Nairn, in Caithness, in the island of Hoy, and in Shetland. They usually form a fringe round the basal beds of the Carboniferous system in the Central Lowlands and along the southern flanks of the Silurian tableland.

CARBONIFEROUS

The records of the Carboniferous formation are of great importance. The succession of sandstones, shales, limestones, coals, and ironstones composing this system have been carefully studied, owing partly to their economic value, and partly to the rich fauna and flora embedded in the rocks. Scotland possesses a large development of these rocks, though owing to subsequent folding and denudation they have been confined mainly to the Central Lowlands and the Border territory. The detailed examination of the Carboniferous areas shows that the strata are arranged in a series of basins much intersected by faults; the crests of the anticlinal folds being occupied by the lower subdivisions of the formation, or by rocks of older date. One of the best examples of this disposition is the great Lanarkshire basin, which is bounded on the north by the Campsie Fells, on the west by the Renfrewshire and Eaglesham Hills, on the south by the Old Red Sandstone of Lesmahagow and Lanark, and on the east by the Lower Carboniferous rocks of Linlithgowshire. The highest subdivisions of the system occupy the centre of the basin, and the lower members crop out round the margin in normal order, except where the regular succession has been disturbed by faults. The same features are displayed in the Midlothian and Ayrshire basins.

The beginning of the Carboniferous period was characterised by a remarkable outburst of volcanic activity, whose relics now form prominent topographical features in the country. In Haddingtonshire they form the Garleton Hills; in Midlothian they are to be found in Arthur's Seat, Calton Hill, Craiglockhart, and at Corston, south of Mid-Calder. They sweep in a great semicircle from Stirling along the Campsie and Kilpatrick Hills to the Clyde at Bowling, thence by the Renfrewshire Hills and Gleniffer Braes to the high grounds near Strathaven—a distance of 70 miles. Still farther west, they give rise to prominent features in Bute, the Cumbraes, Arran, and in Kintyre. Beyond the Silurian tableland they constitute a belt of ground curving round the west side of the basin of Lower Carboniferous rocks in Berwickshire and Roxburghshire, and near the Border territory they can be followed continuously by Langholm and Birrenswark to Annandale. The lavas belonging to this period of vulcanicity consist mainly of various types of basalt, and more acid varieties comprising mugearites and trachytes. An interesting feature connected with these extrusions is the number of orifices still to be found, representing the vents from which the materials were discharged. They are usually arranged in a linear manner, and are now filled with basalt, trachyte, and volcanic agglomerates.

The Carboniferous formation as represented in Scotland may be arranged in four great divisions:—(1) the Calciferous Sandstone series at the base; (2) the Carboniferous Limestone series; (3) the Millstone Grit; (4) the Coal Measures.

The Calciferous Sandstone, when typically developed in the Central Lowlands, comprises two subdivisions: (1) the Cementstone group; (2) the Oil-shale group, the latter passing upwards into the Carboniferous Limestone series. The lower subdivision, typically represented at Ballagan, near Strathblane, is composed of grey, blue, and red shales and clays, white or yellow sandstones and cementstones, from which fragments of plants and fish scales have been obtained. The deposits in the Central Lowlands seem to have been laid down under estuarine or lagoon conditions; but on the south side of the Silurian tableland along the Scottish Border marine bands occur in the strata now grouped with the cementstones, thereby implying incursions of the sea.

The overlying Oil-shale group consists of grey, blue, and black shales, oil-shales, thin bands and nodules of clay-ironstone, limestones, massive white and yellow sandstones, with occasional coal seams. Land plants, ostracods, and fish-remains are abundant, indicating estuarine conditions; while the presence of shales with marine fossils, and of limestones with corals, crinoids, brachiopods, and gasteropods, heralds the marine conditions so prevalent in the lower part of the Carboniferous Limestone series. The members of this group reach a thickness of several thousand feet in the Lothians and in Fife, but in the western districts a part of this sequence of sediments is represented by contemporaneous volcanic rocks, to which reference has been made.

The Carboniferous Limestone series is divisible into three groups: a lower, comprising several beds of limestone, with sandstones, shales, some coals and ironstones; a middle, containing several workable seams of coal, with clay-band and black-band ironstones associated with sandstones and shales, but not with limestones; an upper group of three or more limestones, with thick beds of sandstones and coals. This triple classification is remarkably persistent throughout the Central Lowlands from Fife to Ayrshire, but in the Border region beyond the Southern Uplands the middle coal-bearing group is poorly developed.

The characteristic feature of the lower and upper subdivisions of the Carboniferous Limestone series is the presence of limestones charged with marine organisms. The Hurlet Limestone with its underlying coal and alum shale is usually regarded as marking the base of the series; but the boundary is merely an arbitrary one, for, as already indicated, marine limestones occur in the upper part of the Calciferous Sandstone series. The base of the Upper Limestone group is marked by the Index Limestone—so named because it overlies the valuable coals and ironstones of the middle subdivision, and its top is represented by the Castlecary seam or its equivalent.

No contemporaneous volcanic rocks are associated with the Carboniferous Limestone series in the western part of the midland valley, but in Linlithgowshire they are prominently developed. In that district the volcanic eruptions began towards the close of the Calciferous Sandstone period, and continued till near the close of the Carboniferous Limestone. Occasionally there were quiescent intervals, when corals, crinoids, and molluscs migrated to those volcanic banks and built up bands of limestones and calcareous shales.

Next in order comes a succession of white, yellow, or red sandstones merging into grits and fine conglomerates, fireclays of economic importance, thin limestones, bands of ironstone, and a few thin coal seams. Where no faults intervene, this formation can be traced as a belt of variable width round the margin of the true Coal Measures, a feature which is conspicuously developed in the Midlothian coal-field. In Ayrshire the members of this division are absent or poorly developed, and their place is taken by an interesting series of basaltic lavas and tuffs. Evidence of contemporaneous volcanic action on this horizon has also been obtained in Arran and in Campbeltown.

From a study of the fossil flora Dr Kidston has arranged the Carboniferous rocks in two divisions, the boundary between the two being drawn in the lower part of the Millstone Grit in the Central Lowlands: a classification which has been reached independently by Dr Traquair from the evidence supplied by the fossil fishes. Reference ought to be made to the remarkable assemblage of lamellibranchs, resembling the lamellibranch fauna of the Coal Measures of Nebraska and Illinois of North America, which has been obtained from the lower part of the Millstone Grit and described by Dr Wheelton Hind.

The Coal Measures, which form the highest division of the Carboniferous system, comprise an upper group, consisting of red sandstones, shales, fireclays, marls, and a band of *Spirorbis* limestone, and a lower group of great economic value, containing numerous coal seams, clay-band and black-band ironstones, bituminous shales, fireclays, and white and grey sandstones. From an examination of the fossils it is evident that, during the deposition of the true Coal Measures, fresh or brackish water conditions must have prevailed generally throughout the Scottish basins. Marine bands with brachiopods do occur, but they are rare. The constant repetition of coal seams with sandstones, shales, and ironstones shows that land conditions must have been in the ascendant, followed at intervals by slight submergence.

Within the Silurian tableland of the Southern Uplands a basin of Carboniferous strata rests unconformably on the Silurian rocks and forms the Sanquhar coal-field. From the relations of the younger strata to the older series it is clear that long before the Coal Measures were laid down the old tableland must have been carved into hills and valleys; in short, Nithsdale must have been a valley in Carboniferous time. At the south end of the Sanquhar basin there are some isolated patches of strata belonging to the Carboniferous Limestone series, which, in the adjoining basin of Thornhill, are much more largely developed. When traced northwards these disappear, till in the Sanquhar basin the Coal Measures rest directly on the old floor. Such evidence points to the irregular subsidence of the old tableland of the Southern Uplands.

Evidence has been obtained of the former extension of Carboniferous rocks within the Highland area. At Ardtornish, Morvern, Professor Judd discovered sandstones and shales with thin seams of coal which yielded Carboniferous plants, but we have no means of ascertaining how far these rocks may have extended over the northern land barrier.

Reference must now be made to the intrusive sheets of igneous materials occurring on various horizons, which give rise to conspicuous features in the landscape. One group is composed of olivine-dolerite and teschenite, which, in the Lothians, seem to have been injected into the Lower Carboniferous rocks before the Coal Measures were deposited. Another series, consisting of quartz-dolerite, occurs both as sills and east and west dykes, and belongs in all probability to the close of the Carboniferous period.

Powerful subterranean movements again ensued after the deposition of the highest members of the Carboniferous system. The great succession of sediments that had accumulated during this period were upheaved and subjected to erosion.

PERMIAN AND TRIASSIC

The series of deposits next in order consist of red and grey sandstones and marls that have been referred partly to Permian and partly to Triassic time. In the present stage of inquiry it is difficult to define the precise position in the geological sequence of some of these sediments owing to the absence of definite palæontological evidence. Partly from the lithological characters of the strata and partly from the nature of the organic remains, Ramsay inferred that these rocks were laid down in inland lakes or enclosed basins, thus implying continental conditions.

In the south of Scotland they occupy various isolated areas, as, for example, (1) in the south of Arran, (2) in the centre of the Ayrshire coal-field, (3) at Thornhill, Dumfriesshire, (4) on the shores of the Solway, (5) at Lockerbie, (6) at Moffat, (7) at Loch Ryan. Of special interest are the contemporaneous volcanic rocks underlying these sandstones in Ayrshire and at Thornhill, regarded by Sir A. Geikie as of Permian age. In the region surrounding these volcanic rocks, from Muirkirk to Dalmellington, numerous vents or necks pierce the strata including the highest Carboniferous rocks. Formerly the sediments at these various localities were regarded as of Permian age, but this classification has been modified by more recent research. The discovery of fossils characteristic of the *Avicula contorta* zone (Rhætic) and of Lower Liassic age in Arran led to the grouping of the sandstones and marls in south Arran with the Trias. The red sandstones overlying the volcanic rocks of Ayrshire and those at Thornhill have been ranged with the Trias of south Arran on lithological grounds. Again, the sediments stretching along the coastal belt from Annan to Canonbie have been grouped with the Bunter sandstones of Cumberland, which in the latter region are succeeded by the Keuper sandstones and marls and the Lower Lias. On the other hand, the well-known footprints obtained from the sandstones near Dumfries and Corncockle Moor are regarded by some investigators as proving the Permian age of the sediments in which they are found.

At the base of the great succession of Mesozoic rocks in the Highlands we find a sequence of conglomerates, sandstones, and marls which have been grouped with the Trias. They occur in the north-east of Scotland, the western seaboard of the Highlands, and the Inner Hebrides. The development of these rocks near Elgin is of exceptional importance on account of the remarkable assemblage of reptilian remains which they have yielded. Following the discoveries of Amalitzky in Northern Russia, Mr E. T. Newton and other authorities have suggested that these reptiliferous sandstones belong partly to Permian and partly to Triassic time.

On the western seaboard of the Highlands they occur at Gruinard Bay, where they are thrown down by powerful faults against the Torridon Sandstone. They appear again at Applecross, at Ardnamurchan, in Raasay, and in Sleat, where they graduate upwards into the Lower Lias. Elsewhere, as, for example, at Inch Kenneth, Gribun, Loch Alvie, and Morvern, they are covered unconformably by Upper Cretaceous strata, or by contemporaneous volcanic rocks of Tertiary age.

JURASSIC

The Jurassic rocks of Scotland occur in areas far apart from each other: on the east coast of Sutherland, in the basin of the Moray Firth, along the Western seaboard of the Highlands, and in the Inner Hebrides. They are relics of deposits ranging from the Lower Lias to the Upper Oolite, once extensively developed in the northern part of the kingdom, and preserved from destruction partly by powerful faults and partly by a covering of contemporaneous volcanic rocks of Tertiary age. The largest development in the north-east of Scotland forms a narrow belt, about 16 miles in length, on the coast of Sutherland, from Golspie to near the Ord of Caithness. Patches of Jurassic rocks appear again at the base of the Ross-shire cliffs, to the north and south of the Sutors of Cromarty. In both of these areas they have been let down by faults against the crystalline schists and Old Red Sandstone. The dislocation at the base of the Ross-shire cliffs is a continuation of that which traverses the Great Glen and forms such a striking feature in the topography of the country. The precise age of these faults is uncertain, but they must be more recent than the Upper Oolite, inasmuch as these rocks have been affected by the movements. It is not improbable that the fracture traversing the Great Glen may be of much more ancient date, reaching back to Old Red Sandstone time, if not to an older period.

In the West Highlands the Jurassic and Cretaceous strata occur at intervals over an area measuring about 120 miles from north to south and about 50 miles from east to west. Long after their formation they were buried under a succession of lavas and intrusive sills of igneous rock of Tertiary age. Round the edges of the volcanic plateaux, or where the streams have cut deep trenches through the overlying igneous rocks, the mesozoic strata are exposed anew.

The researches of Professor Judd have shown that in the Jurassic rocks of Scotland there is a constant alternation of estuarine and marine strata, presenting considerable variations at different localities. For example, the estuarine sandstones, conglomerates, and shales at the base of the Lower Lias in Sutherland are overlain with micaceous clays and shelly limestones, with characteristic marine forms; while the lower Oolite is composed mainly of estuarine strata, consisting of sandstones, shales, and coals. On this latter horizon the well-known coal seams are met with, one of them reaching a thickness of 4 feet. Again, in the Middle Oolite there are several important marine zones alternating with estuarine strata; of the former, the "roof-bed" of the Main Coal is an excellent example, consisting of sandstone passing into a limestone charged with ammonites and belemnites belonging to the horizon of the Kelloway rock in Yorkshire. Finally, the Upper Oolites are represented in Sutherland by a splendid development of sandstones, shales, grits, and brecciated conglomerates indicaing estuarine conditions.

In the West Highlands the same recurrence of estuarine and marine conditions is observable, though in a less prominent form. At certain localities sandstones and thin coal seams are to be found at the base of the Lias, while between the Lower Oolite and the Oxford Clay a great estuarine series is intercalated, consisting of sandstones, shales with much carbonaceous matter, and limestones made up of comminuted shells. According to Professor Judd, nearly 3000 feet of Jurassic strata are exposed in the West Highlands from the base of the Lias to the Oxford Clay, to which must be added about 1000 feet of beds representing the Upper Oolite in the north-east of Scotland, so that the total thickness of these rocks cannot be far short of 4000 feet.

CRETACEOUS

Between the Jurassic and Cretaceous strata of the West Highlands there is a prominent unconformability, indicating striking changes in the physical geography of the region and extensive denudation of the deposits that had accumulated during previous periods. During this interval the floor of the sea must have been elevated and the Jurassic sediments must have been removed, either in whole or in part, from certain localities. The precise date of this elevation cannot be definitely determined. As already indicated, no representatives of the Upper Oolite have been detected in the West Highlands, the highest Jurassic rocks being of Middle Oxfordian age. The continuity of the record in that region is further interrupted by the absence of equivalents of the Weald and of the Lower Greensand, for the lowest Cretaceous rocks yet recorded belong to the Upper Greensand. These consist of glauconitic sands, becoming calcareous and passing into shelly limestones, belonging to the *Pecten asper* zone. According to Professor Judd, these strata are succeeded by estuarine sandstones followed by beds of white chalk with flints containing *Belemnitella mucronata*, while at the top of the series occur sandstones and marls with plant-remains and thin seams of lignite. From the character of the strata in this brief succession it is evident that they point to an alternation of estuarine and marine conditions similar to that which characterised the deposition of the Jurassic rocks.

In the north-east of Scotland relics of Cretaceous strata have been found at various localities, but not in the position in which they were originally deposited. The evidence suggests that they have been more or less affected by glacial action since their formation. One of the best-known localities is at Moreseat in Aberdeenshire, where a fine-grained sandstone with colloid silica has yielded fossils characteristic of the Aptien stage of France or the Lower Greensand of the Isle of Wight. Lower Cretaceous fossils with a Neocomian facies have been recently recorded by the Geological Survey from a patch of concretionary sandstone in Caithness. Such evidence is of importance, as it points to the deposition of Lower Cretaceous strata either on or near the north-eastern seaboard of Scotland. In the drifts of the counties of Aberdeen, Banff, and Caithness numerous blocks of chalk and chalk flints with fragments of *Inoceramus* have been found. It is highly probable, therefore, that Upper Cretaceous rocks may occupy portions of the sea floor bordering these north-eastern counties.

TERTIARY

At the close of the great succession of mesozoic rocks there is a further blank in the geological history of Scotland. The records belonging to older Tertiary time point to extraordinary volcanic activity, when sheets of lava were piled on each other to a considerable depth, with occasional intercalations of beds of limestone and shale containing plant-remains, which were deposited during intervals of quiescence. These volcanic plateaux stretch over an extensive territory, reaching from Antrim by the Inner Hebrides to the Faroe Isles. In the West Highlands they are typically developed in Skye, Mull, Ardnamurchan, Morvern, Eigg, Muck, and Canna. The researches of

Mr Harker in Skye have shown that the volcanic sequence there consists almost wholly of lavas of basic and sub-basic composition, except on the northern border of the Cuillins, where acid lavas and tuffs have been recorded. In places at the base of the volcanic series there are local accumulations of agglomerates and tuffs, but these are of rare occurrence in the great succession of lavas.

Before the outbreak of vulcanicity the strata of pre-Tertiary age were subjected to earth-movements and extensive denudation. Hence the volcanic rocks rest, in places, on different members of the Jurassic and older systems, and in other localities on Upper Cretaceous strata.

The volcanic rocks are pierced by masses of coarse gabbro typically represented in the Cuillin Hills, and by bosses of granophyre which form the well-known conical mountains between Sligachan and Broadford. These plutonic rocks likewise appear in Rum, Ardnamurchan, Mull, and St Kilda. Another characteristic feature of the period is the injection of sills of dolerite, which in places pass transgressively from one horizon of the volcanic sequence to another. But perhaps the most remarkable feature outside the volcanic plateaux is the extraordinary number of basalt dykes filling rents or fissures, extending for miles across the surface of the country. They have been traced from Yorkshire to the West Highlands, and they stretch over an area ranging from the north of Ireland to the north of Scotland and probably to Orkney. According to Professor Judd, the lavas were discharged from great central volcanoes, the relics of which are now represented by the plutonic rocks of Skye, Rum, Mull, Ardnamurchan, and St Kilda. On the other hand, Sir A. Geikie contends that the lavas issued from innumerable fissures, a view which has been adopted by Mr Harker in the Geological Survey memoir on "The Tertiary Igneous Rocks of Skye."

The only organic evidence bearing on the age of the great basaltic plateaux is supplied by the leaf beds occurring between the lava-flows at Ardtun in Mull. The researches of Mr Starkie Gardner point to the conclusion that the flora may be of Eocene age, and hence the extrusion of the volcanic rocks may belong to the earliest division of Tertiary time.

Evolution of the Topographical Features of Scotland in Pre-Glacial Time

A careful study of Scottish topography, especially of the river systems, leads to the theoretical conclusion that the existing features have been carved out of a solid block, the upper surface of which must have sloped towards the south-east, as suggested by Mr Mackinder in his volume on "Britain and the British Seas."

From the brief outline already given of the geological history of the country, it is evident that the youngest rocks entering into the structure of this plateau consist of the Eocene volcanic and plutonic rocks of the West Highlands with the accompanying series of basalt dykes. Hence the elevation of the plateau must date from that period, and the excavation of the valley systems must have been effected during the later divisions of Tertiary time. The Mesozoic sediments must also have entered largely into the structure of the block, though they have been mostly removed by denudation. Much of the evidence relating to the topography of the country at the close of the prolonged volcanic activity in Eocene time is, as might be expected, both fragmentary and indefinite, but the available data bearing on the development of the surface features of Scotland can be satisfactorily explained on the foregoing hypothesis.

In Scotland three great planes of denudation can be recognised:—(1) the High Plateau or peneplain, varying from 2000 to 3000 feet in height, with Ben Nevis, the Cairngorm Mountains, and other peaks appearing as monadnocks; (2) the Intermediate Plateau, the upper limit of which is about 1000 feet; (3) the Continental Shelf, extending to the 100-fathom line at the edge of the Atlantic Rise and the Faroe Channel. Each of these represents a protracted period of denudation, with the sea acting, in each case, as the base-level of erosion.

At the initiation of our river systems, Scotland lay mostly, if not wholly, on the south-east slope of the uplift, and formed part of a continental area continuous with Ireland on the south-west and with Scandinavia on the north-east. Across this inclined plateau the consequent rivers drained south-eastwards into a Miocene sea stretching from the north of France to beyond Schleswig Holstein. The north-west declivity of this land surface extended to the edge of the Continental Shelf, or, in other words, to the edge of the Atlantic-Arctic Ocean Rise, and was therefore steeper and shorter than the other. Hence the consequent rivers flowing in a north-westerly direction had greater erosive power than those draining to the south-east. Thus they were able to entrench themselves in valleys and ultimately, by cutting backwards, to encroach on the domain of those flowing to the south-east.

On the mainland of Scotland subsequent denudation has cut the High Plateau into three main blocks, in each of which similar conditions of drainage occur, viz.: (1) a long drainage system towards the south-east along the remains of the old consequent valleys; (2) a shorter and steeper one to the north-west by obsequent streams running in the old consequent valleys; (3) a subsequent easterly and westerly drainage system due in large measure to the grain of the rocks. These blocks are situated as follows:—

1. The Northern Block, comprising the area to the north-west of the Great Glen and Loch Linnhe.
2. The Central Block, extending from the Great Glen south-eastwards to the Firths of Forth and Clyde.
3. The Southern Block, stretching from the low plain between the Firths of Forth and Clyde to the English Border and the Solway Firth.

The dominant factor that led to the sculpturing of the continental uplift into these individual masses was the existence in each case of a core of crystalline schists or older palæozoic strata surrounded by younger formations with feebler powers of resistance. The former still constitute the elevated portions of these blocks, while the weaker strata have given rise to the existing plains and lowland areas. Shatter belts situated along lines of fault or dislocations of the strata have exercised a considerable influence in producing the isolation of these individual masses. The development of the lowland belts in the north-eastern areas was aided by the resuscitation of ancient land surfaces which had been deeply buried by younger strata.

SCULPTURE OF THE NORTHERN BLOCK (NORTH-WEST HIGHLANDS)

As might be expected, the remnants of the old consequent drainage system are best preserved in the two northern blocks. A study of an orographical map of Scotland shows that in the area north-west of the Great Glen the main valleys occupied by the original consequent rivers are continued to the West Coast, though now partly drained by obsequent streams. In such cases the cols form low passes. A further study of the behaviour of the watershed of the Northern Block tends to support this conclusion. For example, the water-parting bends far to the east along the valleys occupied by the main streams, while in the case of the tributaries it swings far to the west, thus showing that the south-easterly flowing streams had first possession of the ground.

The geological evidence indicates that the grain of the crystalline schists had little if any influence in determining the trend of the consequent streams, which is transverse to the strike of these schists. An apparent exception occurs in the Laxford area of Lewisian gneiss, where the strike of the gneiss coincides with the trend of the valleys; but the geological history of that region shows that the valley system must have been initiated at a time when the Lewisian rocks were buried under strata the strike of which ran N.N.E. and S.S.W.

Shatter belts accompanying more or less vertical lines of fault and trending in two directions—one N.W. and S.E., and the other N.E. and S.W.—helped to some extent to produce the drainage system in this northern region. The lines of fracture along Loch Maree and Loch Inchard may be cited as instances of the former, and those extending from Glenelg to Strath Conan and along the Great Glen are striking examples of the latter.

On the eastern portion of the Northern Block the grain of the younger strata tended to deflect the rivers from their south-east course. The disposition of the Old Red Sandstone and the mesozoic strata not only shows that they must have entered largely into the structure of the High Plateau, but also that they were thrown into two basins intersected by the Great Glen fault, the axes of these basins being approximately north-east and south-west. In these weak structures the grain of the rocks became a prominent factor in deflecting the rivers from their south-east course, and, during the period of maximum elevation, in reducing the area to a plain in which the old divides were nearly obliterated. From a study of charts of the sea floor it would appear that two main trunk rivers were established, following the strike of the weak strata and the shatter belts produced by the Great Glen fault and the dislocation skirting part of the Sutherland coast. The more northerly one seems to have flowed parallel to the present coast-line of Sutherland, Caithness, and Orkney, intercepting all the consequent streams as far south as the Dornoch Firth and ultimately draining into the Faroe Channel; the other parallel to the coast of Nairn, Moray, Banff, and Aberdeen, following what is probably the strike of the secondary strata, and at one time, either directly or by means of longitudinal tributaries, tapping all the consequent rivers westwards to Loch Eil.

The Cromarty Firth is evidently the submerged valley of a subsequent stream following the centre of the syncline between the two great shatter belts, which intercepted and deflected all the old consequent streams now draining into it. Again, the main subsequent river between Inverness and Nairn, whose course is now covered by the Moray Firth, tapped and deflected the consequent stream which formerly occupied the site of the Beauly Firth.

Along the eastern portion of the Northern Block the intermediate plateau and the coastal belt are mainly carved out of Old Red Sandstone, but in certain localities they consist of the old floor of crystalline schists from which the covering of Old Red Sandstone has been removed. Various outlying masses of this formation furnish striking proof of its former extension over the high plateau of the Northern Block, as for instance in Strath Vaich, Ross-shire, the heights on either side of Strath Brora, and the Griams in Sutherland.

The development of the plain of North Sutherland and Caithness resembles in many respects that of East Sutherland and Easter Ross. Here the weak strata that remain are composed of Old Red Sandstone. A main trunk stream appears to have cut back from the Faroe Channel, west of and parallel to the long axes of Shetland and

Orkney, thence westwards along the strike of the Old Red Sandstone strata by the north coast of Sutherland. The tributaries of this river in some cases followed the pre-Old Red Sandstone valleys in the old floor of crystalline schists, filled with the basement rocks of that formation. As these ancient valleys coincide with the strike of the schists, the streams, by cutting backwards along the grain of the rocks, have been enabled to intercept a great part of the head-waters of the original south-east consequent streams and deflect them towards the north. The River Naver is an excellent example, for it has succeeded in capturing the upper portion of the Helmsdale consequent stream from below Loch Naver to the sources of that river.

Reference has already been made to the structural evidence suggesting that the subsequent or longitudinal rivers draining into the Moray Firth intercepted the old consequent streams of the Northern Block as far west as Loch Eil. While this was in progress, however, the weaker mesozoic strata overlying the palæozoic and schistose rocks in the west were also being removed by rivers cutting back from the Atlantic Rise, and forming the plain of the Minch, during the period of the production of the Continental Shelf. Another drainage system seems to have followed the line of the North Channel and reached the shatter belt of the Great Glen somewhere about the Firth of Lorne. Along this line of weakness it seems to have cut backwards, intercepting in turn the consequent streams of the Northern Block. The order in which the streams were appropriated is probably shown by the decreasing depth of the valleys from west to east. The Sound of Mull, Loch Eil, and Loch Arkaig represent depressions initiated by the old consequent streams of the Northern Block.

The prominent physical features in the Outer Hebrides are due to a ridge of Lewisian Gneiss which has been isolated by the denudation of the western rivers draining to the edge of the Continental Shelf. Skye, which originally formed part of the mainland, has been disconnected by similar processes of denudation. The mountainous tracts of that island, of Rum, and Mull are due partly to the resistant nature of the Tertiary plutonic masses and associated volcanic rocks, and partly to the influence of faults which have brought up portions of the old floor of crystalline schists and overlying Torridon Sandstone.

As already indicated, the 100-fathom line was the base-level of erosion at the period of maximum elevation. Inwards, however, the plain now represented by the Minch acted as the base-level of the obsequent streams. Owing to their steeper gradient, the rivers flowing west ultimately developed flat-bottomed valleys, and, as they pirated some of the head-waters of the eastern streams, the volume and erosive power of the east-flowing rivers were diminished *pari passu* with the increase of energy of those in the west. It is an interesting and suggestive fact that the Northern Block is trenched by cross valleys running from sea to sea, the passes at the watershed being mostly below 800 feet level, while the mountain masses on either side often rise to 2000 or 3000 feet above sea-level. These topographical features may reasonably be accounted for by the relation of the obsequent streams flowing west to the old consequent rivers draining eastwards across the continental uplift.

SCULPTURE OF THE CENTRAL BLOCK (GRAMPIAN HIGHLANDS)

In the Central Block the conditions affecting the evolution of the topography of the region resemble to some extent those just described. A core or axis of crystalline schists trending north-east and south-west, with plutonic igneous masses, forms the dominant feature, which is surrounded by less resistant sedimentary strata and contemporaneous volcanic rocks.

As might be expected, the remnants of the old consequent streams are best preserved in the centre, and along the south-east slope of this block, especially along a belt of country several miles broad near the Highland Border. This belt is composed mainly of highly inclined schistose grits of great durability, flanked by weaker strata to the north-west and south-east, and is traversed by consequent or transverse streams flowing towards the south-east. Within this belt the rivers have been occupied in deepening their valleys. There has been no capture from neighbouring consequents, which is in marked contrast with the behaviour of the same streams on the north-west and south-east, as will be shown in the sequel.

North of this belt the grain of the rocks has had a powerful influence in modifying the drainage system, so that the Tay-Garry, about the centre of the block, is the only old consequent stream that extends back continuously into the interior of the region. The rivers flowing into the Moray Firth on the north-east, and the sea-lochs and sounds on the west, illustrate the potency of this factor in a remarkable manner. In the most northerly belt of the Central Block there are remnants of the old transverse valleys now occupied by obsequent streams draining into the Moray Firth.

The plain on the south-east side of the Moray Firth is due to the removal, in whole or in part, of a succession of comparatively weak strata separated from each other and from the underlying crystalline schists by planes of denudation and unconformability. The Mesozoic strata and the Upper Old Red Sandstone formed part of the original covering that has now been removed; but the representatives of the

Middle Old Red Sandstone had probably the greatest development among the younger formations in the Central Block. Indeed, the slope of the country from the High Plateau to the Moray Firth is partly due to the resuscitation of the old floor of crystalline schists on which they were laid down. The apparently abnormal direction of the shore-line from Fort George to Kinnaird Head, bounding the present plain, is probably due to the strike of the planes of unconformability in that region, at the base of the Trias, at the base of the Upper and of the Middle Old Red Sandstone.

The drainage towards the Moray Firth was probably established at an early date. The disposition of the Old Red Sandstone and younger strata and the trend of the shatter belts favoured the action of the subsequent streams, so that the successive divides were broken down and the disjointed members of the old consequent rivers were made tributaries of the subsequent system of drainage. The Spey is the most striking example, for it seems to have been able to cut backwards so as to intercept the old consequent streams of the Northern Block as far west as Loch Eil, though subsequently compelled to yield part of this ground to invaders from the north and west, especially to tributaries of the Great Glen.

The plain in Eastern Aberdeenshire is evidently due to the removal of Old Red Sandstone and probably mesozoic strata. The trunk river that received the drainage of the greater portion of this low-lying tract ran parallel to the existing eastern coast-line of the Northern Block, and intercepted all the consequent streams probably as far south as the Tay. The Ugie, the Ythan, and the Ury are remnants of old consequent streams that crossed this plain.

The Dee valley has been determined largely by the grain of a belt of crystalline schists lying between large masses of granite on either side. The history of the Upper Dee and Don suggests that these rivers were the first to occupy that portion of the High Plateau. For it has been clearly shown that the Feshie captured the headwaters of the Geldie, and that the Avon beheaded the Upper Don at Inchrory, thus deflecting the drainage at these points towards the Spey. The Tilt—a tributary of the Tay—has also pirated the Tarf from the Dee.

The behaviour of the rivers in that part of the Central Block lying to the south of the Highland Border fault between Stonehaven and the Firth of Clyde has been studied and described by several observers in recent years. Brief allusion may here be made to some of the salient points and their bearing on the evolution of the topography of that region.

The Lower Old Red Sandstone along this belt consists of a succession of conglomerates, sandstones, and marls with intercalated volcanic rocks, the latter being typically developed in the Ochils and Sidlaw Hills, where they form a well-marked arch. Between this outer range and the Highland Border, the overlying sedimentary strata, composed of sandstones and marls, lie in a trough now represented by Strathmore and the Howe of the Mearns. The Upper Old Red Sandstone rests with a strong unconformability on the lower division of that formation, outliers of it being found at intervals on the coast of Forfarshire and Kincardineshire. In this region, as in the Pentland Hills, there is clear evidence for maintaining that the members of the Lower Old Red Sandstone were folded and denuded before the strata of the upper division were deposited.

A glance at a geological map shows that the rivers Tay, North Esk, and Bervie traverse the marginal belt of the Highlands in deep consequent valleys, thence cross the plain occupied by the Lower Old Red conglomerates, sandstones, and marls, and breach the volcanic arch of the Ochils and Sidlaw Hills. Ultimately they joined the trunk river that flowed northwards along the East Coast. It is obvious that, at the time of the initiation of these consequent streams, Strathmore and the Howe of the Mearns had no existence. There must have been a graded slope from the margin of the Highlands towards the south-east. The behaviour of the rivers on entering the belt of weak strata along Strathmore reveals the processes by which the existing topographical features were brought about. Thus the Isla, a subsequent tributary of the Tay, by working north-eastwards along the weaker Lower Old Red strata, has captured several of the old consequent streams draining the Highland Plateau from the Ericht to the Upper Isla. The deflection of these waters into the Tay led to the initiation of obsequent streams draining into the Isla on the north-west slope of the Sidlaw Hills, and the formation of wind-gaps across the volcanic arch, of which the hollow traversed by the Dundee and Alyth Junction Railway is a good example.

In like manner the South Esk, which may be regarded as a subsequent tributary of the North Esk, by working south-westwards along the same weak strata has tapped the old consequent streams of the Highland Plateau as far to the south-west as the Prosen. Again, the Luther Water, a subsequent branch of the North Esk from the north-east, has captured several minor consequent rivers. Wind-gaps resulting from this deflection are still to be found in that portion of the Sidlaw range; one conspicuous example occurring to the east of Marykirk. Similar phenomena on a smaller scale are observable where the Bervie River crosses the Howe of the Mearns.


Pentland Firth
Duncansby Hd.
John O'Groats
Butt of Lewis
Sinclair Bay
Wick
Flannan Is
Loch Roag
Stornoway
Lewis
Loch
of Caithness
OUTER HEBRIDES
Taransay
Harris
Sound of Harris
Little Minch
N. Uist
Benbecula
South Uist
Barra
L. Snizort
Elgin
Loch Bracadale
Canna
Cuillin Sd
Rum
Banff
Troup Hd.
Kinnaird Hd.
Fraserburgh
Ugie
Peterhead
Buchan Ness
Deveron
Ythan
Don
Aberdeen
Girdle Ness
Dee
58
57

OROGRAPHICAL AND BATHYMETRICAL MAP OF SCOTLAND.

SCULPTURE OF THE MIDLAND VALLEY

Although an arbitrary line extending from the Firth of Forth to the Firth of Clyde was chosen as the boundary between the Central and Southern Blocks, we may here refer to the Midland Valley as a whole, as both sides have many features in common. This tract, measuring about 120 miles in length and about 50 miles in breadth, is bounded on the north-west by the Highland fault reaching from Stonehaven to the Firth of Clyde, and on the south-east by the fracture defining the northern margin of the Southern Uplands.

It has already been shown in the geological section that the sediments entering into the structure of the Midland Valley belong chiefly to the Old Red Sandstone and Carboniferous formations, with which are associated contemporaneous volcanic rocks. The strata are arranged in the form of a compound syncline with subsidiary minor folds, the longer axes of which are more or less parallel to the bounding faults, thus giving rise to a prominent grain of the rocks in a north-east and south-west direction. There is ground for maintaining that the Midland Valley was originally buried under Triassic and younger sediments, which, for the most part, have been removed by denudation.

As soon as the trunk system of drainage had been established at the time of greatest elevation, the weak sedimentary strata, attacked in flank, soonest gave way, and the system of drainage characterised by subsequent streams gained the ascendancy. The volcanic plateaux offered greater resistance to the denuding agents, and hence their outcrops assumed the form of intervening ridges, while the areas occupied by the sediments have been worn down into plains from which rise isolated hills and knobs representing major igneous intrusions and volcanic necks. These hills of circumdenudation are of extreme interest, as they are still breached by the old consequent rivers draining the Highland Plateau, and they contain wind-gaps indicating the deserted channels of some of these consequent streams.

Reference has already been made to the behaviour of the Tay, North Esk, and Bervie rivers in the north-east portion of the Midland Valley. The Forth above Stirling has had a similar history to that of the Tay during the period of greatest elevation. It seems to have formed an affluent that passed southwards close by St Abb's Head to join a stream that drained the Tees, the combined rivers flowing north-eastwards across the plain of the North Sea. The old buried channels of the Forth and of its tributaries the Bonny, the Devon, and the Almond plainly indicate the greater elevation of the land during the evolution of the present topographical features. Like the other east-flowing streams, the Forth occupied the ground first, and, by working along the weak belts, captured the old consequent rivers of the Central Block as far west as Loch Long. Subsequently the streams working inwards from the west have regained part of this drainage area.

Striking examples of wind-gaps are represented by Glen Farg and Glen Eagles in the Ochils, the Endrick-Carron hollow across the Campsie Fells, and the Blane-Glazert depression between the Campsie and Kilpatrick Hills.

On the south of the Midland Valley the Pentland Hills form another ridge of circumdenudation. The course of the river Lyne, which traverses this ridge, furnishes remarkable evidence of the former existence of topographical features that have long since vanished. Rising on the north side of this chain, where it has been beheaded by tributaries of the Water of Leith, it still flows through these hills as a consequent stream, maintains the old course across the West Linton plain, and enters the Southern Uplands in a matured valley. In this chain there are two additional instances of old consequent rivers, the North Esk and its tributary the Glencorse Water, which, beginning on the northern slope of these hills, cross them in deep valleys. On emerging from the ridge of Lower Old Red Sandstone volcanic rocks, the Glencorse Water enters the plain occupied by Carboniferous strata where it has been captured by the Esk and made tributary to the Forth.

Brief allusion may now be made to the probable development of the western drainage of the Midland Valley. The trunk river flowing along the course of the North Channel, by working its way backwards across the mesozoic strata spread over the plain now occupied by the Firth of Clyde, captured the old consequent streams up to that now represented by the lower part of Loch Fyne. By following the weak strata of the Upper Old Red Sandstone and the Cementstone Group beneath the Carboniferous volcanic rocks of Renfrewshire, it deflected the old drainage system of the Cowal region and the heights near Loch Lomond, which, for a time, flowed eastwards to the Forth. Beyond this point it probably was aided in its recession by taking advantage of one of the hollows established by a tributary of the Forth. On reaching the Clyde basin above Dalmuir it captured the lower portion of the river Clyde, which, as an obsequent stream, had for a time discharged its waters into the Forth.

SCULPTURE OF THE SOUTHERN BLOCK (SOUTHERN UPLANDS)

The Southern Block, as already indicated, has a core of Silurian strata, with a persistent north-east and south-west strike, pierced by large igneous masses, and more or less surrounded by less resistant sediments, whose remains are traceable across parts of the plateau. Remnants of the old consequent river system established before the isolation of the three blocks are still preserved in the southern region. of which the Nith is the finest example.

On the south side of the plateau the subsequent or longitudinal system of drainage has been set up by rivers attacking the weak sediments in flank. Thus the Tweed, working from the east, along the less resistant Carboniferous and Upper Old Red Sandstone strata, eventually followed the grain of the Silurian rocks, and by these means was able to intercept all the old consequent drainage westwards to beyond the centre of the plateau. South of the plain of the Merse, remnants of the old transverse streams again appear; for the Coquet, Rede, and Tyne, rising on the north side of the Cheviot range, cross it in well-marked hollows.

The tributary of the North Channel River, flowing along what is now the plain of the Solway Firth, cut its way backwards along the younger sediments. In the higher reaches of this stream, the Liddel, by following the grain of the Lower Carboniferous rocks, captured some of the smaller streams belonging to the Tweed system. The Solway-Liddle tributary deflected, from Luce Bay eastwards to the Esk, the old consequent rivers that crossed the Southern Block.

On the north side the development of the Central Plain has obliterated most of the courses of the old consequent streams, but the Doon on the west and the Clyde in the middle have maintained the old direction of their valleys by becoming obsequent streams. Frequent reference has been made in geological literature, and particularly by Sir A. Geikie, to the remarkable course of the river Nith. The infant stream rises on the north slope of the Southern Uplands, and flows northwards from the Silurian plateau to the plain of Carboniferous strata, along which it runs in an easterly direction for five miles to New Cumnock, where it changes its course to the south-east in the direction of the Solway. The easterly course of the stream above New Cumnock was doubtless determined by a subsequent tributary of the old consequent river that crossed the plateau before the isolation of the three blocks.

As in the northern and central regions already described, there is evidence to show that, in the Southern Block, the eastward-flowing streams extended farther to the west than at present, and that portion of their territory has been captured by rivers draining to the west and south-west. The Tweed may be instanced as an excellent example of these mutations. By means of its tributary, now represented by the Biggar Water, it cut backwards till it captured the old consequent Clyde, a large part of which it rendered obsequent. It also appears to have receded far to the west by appropriating the upper portion of this same consequent, of which the Duneaton and Douglas Waters were already subsequent tributaries. As the North Channel River and the Lower Clyde cut backwards through weak Carboniferous strata more rapidly than the tributaries of the Tweed among the durable Silurian rocks, they eventually captured the territory which had been temporarily annexed by the Tweed.

A feature of special interest in connection with the topography of the Southern Block is the resuscitation of old palæozoic land surfaces in the course of the development of the existing physical features. Thus we find evidence of the existence of a transverse valley system of pre-Upper Old Red Sandstone age, of which Lauderdale is a characteristic example. In this ancient hollow, sediments of Upper Old Red Sandstone age were laid down which are now being eroded by the Leader Water. Another, but less obvious, valley is still buried under sandstones and conglomerates belonging to the same period, stretching across the Eastern Lammermuirs from Longformacus to Dunbar.

Nithsdale and Loch Ryan are instances of pre-Carboniferous hollows, for they are still floored in part by Carboniferous strata which are remnants of more extensive deposits. In the case of Loch Ryan, the Carboniferous rocks must have undergone considerable denudation before the deposition of the overlying red sandstones of Permian or Triassic age. Annandale furnishes striking evidence of a valley system dating back to palæozoic time, as the breccias (Permian or Triassic) which floor the present valley near Moffat contain blocks of fossiliferous Lower Carboniferous strata that once filled these hollows. The hollow of Eskdalemuir is another example, for the deep staining of the Silurian rocks points to the removal by denudation of red strata from that area. Again, in the Abington region outlying patches of Carboniferous strata and breccia of Permian or Triassic age rest unconformably on the old Silurian floor in such a manner as to suggest that the Clyde took advantage of these weak sediments while cutting backwards as an obsequent stream.

Along the western edge of the Upper Old Red Sandstone south of Melrose there are examples of a secondary system of smaller valleys following the grain of the Silurian rocks, which contain outliers of Upper Old Red Sandstone. Recent observations point to the existence of such sediments in the valley of the Ettrick far to the west of Selkirk.

The relation of the Upper Old Red Sandstone to the Silurian rocks along the northern slope of the Moorfoot and Lammermuir Hills shows that part at least of the steep northern declivity was a feature established in Upper Old Red Sandstone time. Similar instances of the resuscitation of the old land surfaces along the north-west face of the Cheviots might be adduced, where Upper Old Red Sandstone and Carboniferous strata rest on an ancient platform of Silurian and Lower Old Red Sandstone volcanic rocks. South of Jedburgh, there are isolated hills carved out of Lower Old Red Sandstone lavas at the close of that period, which are now restored by the partial removal of Upper Old Red strata that once enveloped them.

The evidence now adduced, in brief outline, reveals the extensive denudation of the ancient Silurian tableland during various geological periods, and the behaviour of the Triassic sediments indicates that mesozoic strata entered into the structure of the Southern Uplands and of the Midland Valley at the time of the initiation of the river systems during the Tertiary period.

Glaciation of Scotland

In the preceding section, dealing with the evolution of the topography of the country, reference has been made to the fact that in pre-glacial time Scotland stood at a higher elevation above the sea-level than it does at present. Mining operations in the basins of the Forth and Clyde have conclusively shown that coal-seams have been worked up to the margins of pre-glacial river-channels now filled with various superficial deposits. For example, the bottom of one of these ancient river courses at Grangemouth is 240 feet below present sea-level.

But in Scotland no deposits of later Tertiary time have yet been detected which might throw light on the changes that preceded the advent of the Ice Age. In England, however, valuable evidence is supplied by the later Tertiary formations. The older Pliocene deposits on the Norfolk coast, which are all of marine origin, were laid down at some distance from land, in a warm temperate sea. On the other hand, the Newer Pliocene strata indicate a gradual refrigeration of climate. Professor James Geikie and Mr Clement Reid have shown that the land and fresh-water mollusca of the lower part of the Red Crag are mainly of South European types, while those of the higher zones from the Upper Red Crag to the Weybourn Crag present a more northern facies. It is evident, therefore, that during these stages the seas of East Anglia must have been connected with the Arctic Ocean, and that the North Sea may have been occupied by an Arctic fauna. These facts point to the submergence of the Continental Shelf and the severance of Britain from Scandinavia across the plain of the North Sea.

The succeeding Cromer Forest Bed, consisting of a series of estuarine and lacustrine strata laid down under temperate conditions, points to a greater extension of land surface than now prevails, the southern half of the North Sea forming a plain watered by the Rhine. The *Yoldia* (*Leda*) *myalis* bed, resting transgressively sometimes on the Forest Bed and sometimes on the Weybourn Crag, indicates a slight depression of the estuary, and the prevalence of boreal and arctic conditions. At the top of this sequence we find the arctic fresh-water bed with plant-remains, proving a great lowering of temperature, which, in the opinion of Mr Clement Reid, may have allowed the seas to be blocked with ice during the winter, and glaciers to form in the hilly districts. From these data it would appear that at this stage in Norfolk the relative position of land and sea must have been much the same as at the present time. Evidence tending to support this conclusion has been recently obtained in the south of Ireland. In view of these data, there can be little doubt that the refrigeration of climate which culminated in the glacial period was a slow and gradual process.

Before proceeding to describe the glacial phenomena of Scotland, we ought to call special attention to the fact that the main valley systems of the country and the dominant features of the High Plateau had been determined in pre-glacial time. The prolonged glaciation of the mainland and the outer islands produced important modifications of these physical features, which have survived to the present day.

Throughout Scotland there is overwhelming evidence of the intense glaciation of the northern part of Britain. The phenomena point to (1) a period of maximum glaciation, when the Scottish and Scandinavian ice-sheets coalesced on the floor of the North Sea; (2) a period of valley glaciers which became confluent in certain areas. Each epoch is characterised by different centres of ice dispersal, by different methods of ice erosion, and by distinctive glacial accumulations.

MAXIMUM GLACIATION

During the period of maximum extension the ice must have enveloped the whole country and radiated from three great centres; the first being situated in the Northern Block, to the north-west of the Great Glen; the second, in the Central Block, between the Great Glen and the eastern border of the Highlands; and the third, in the Southern Uplands. The ice-shed of the Northern Block ran approximately north and south, and over a large part of the area lay to the east of the present watershed; that of the Central Block appears to have had a short axis trending generally east and west, and situated in the region of the Moor of Rannoch; while that of the Southern Block ran in a north-east and south-west direction along the crest of the Southern Uplands, from Broadlaw in Peeblesshire to the Merrick in Kirkcudbrightshire. Beyond these main areas of ice dispersal there were minor centres, as, for instance, in the Cuillin Hills in Skye and in the Cheviots.

The ice radiating from the three main centres coalesced on the intervening plains, and moved towards the Continental Shelf on either side. Thus the ice from the Eastern Highlands invaded the Midland Valley, and met the sheet from the Southern Uplands as far south as the Pentland Hills and the Lammermuirs on the east, and Muirkirk and New Cumnock on the west; the confluent streams moving towards the North Sea and the Firth of Clyde. Again, the glaciers from the mountains of Ross and Inverness crossed the plain of the Moray Firth and invaded the coastal belt of Nairn, Elgin, and Banff.

As already indicated, the ice flowing eastwards off the mainland of Scotland united with the Scandinavian *mer de glace* on the floor of the North Sea. One branch of the combined ice-field moved northwards from the Firth of Forth, and, skirting the coast-lines of Kincardine and Aberdeen, ultimately overrode Caithness, Orkney, and Shetland on its onward march to the Atlantic. The southern branch, pressed back by the Scandinavian sheet, was deflected southwards, and invaded the plains of England south of Flamborough Head.

On the north coast of Sutherland the ice advanced in a north-west direction under the influence of the *mer de glace* that passed over Caithness and Orkney. Along the western seaboard, from Cape Wrath to Kintyre, the general movement was outwards across the Continental Shelf, with important local deflections due to the physical features of the Western Isles. During the maximum extension the ice from the mainland crossed the Minch and overtopped the Outer Hebrides; it coalesced with the local sheet of the Cuillin Hills, and the combined streams surmounted the basalt plateau to the north of these mountains.

South of Loch Fyne the Highland stream advanced towards the Firth of Clyde, where it united with the ice from the western portion of the Southern Uplands, and moved southwards towards the Irish Sea, a branch being deflected westwards across Kintyre under the influence of the sheet radiating from the north of Ireland.

No reliable estimate can be given of the thickness of this extensive ice-field, but it must have reached great dimensions when none of the peaks of the mainland rose as nunataks above the surface of the ice, when the outlying islands were overtopped and the intervening sounds were occupied by the *mer de glace*. Professor James Geikie suggests that some of the mountains in Harris may have protruded above the ice-field.

The phenomena attributable to the ice during the period of maximum extension may thus be briefly summarised:—(1) The grinding up of the cover of rotted rock and loose debris due to subaerial waste in the later divisions of Tertiary time; (2) the scooping out of loosened material along shatter belts or great lines of fracture; (3) the differential erosion of the rocks entering into the geological structure of the country, dependent upon the variation in the powers of resistance of the strata, on the thickness and slope of the ice, and on the grinding power of its basal layers charged with sand, clay, and stones; (4) the consequent steepening of opposing rock-faces, of escarpments, of mountain sides, the deepening of valley floors, the planing of cols, and the general lowering of the rocky plateaux.

Thus we find in those cases where the trend of the valley coincided with the direction of ice-flow during the maximum extension, that V-shaped valleys became U-shaped—a form characteristic of glaciated mountain regions. The projecting spurs were removed, and a lack of adjustment was produced between the over-deepened trunk valleys and their tributaries. The latter are termed hanging valleys, owing to the steep gradient at which they enter the trunk valleys. Another result of the abrasion by the ice, which will be more fully dealt with in the sequel, was the production of one or more rock-basins along the course of the valley, dependent upon the topographical features, the geological structure, and the erosive power of the ice in each case.

The distribution of the ice in the region situated to the north-west of the Great Glen, where the ice-shed lay to the east of the watershed over part of the area, caused a drainage of ice across the low cols in the old transverse valleys. Hence, owing to the excessive erosion which they experienced, these low cols form flats often studded with lochans, many of which are true rock-basins. Where the side streams debouch on the cols they form deltas, which deflect the drainage to the east or west, or impound the waters and thereby give rise to lakelets.

The glacial accumulation characteristic of this period is the boulder clay, with lenticular sheets of sand and gravel, which forms an extensive covering in the Lowlands, and stretches up the valleys of the Southern Uplands, and to a limited extent in the Highlands. Its remarkable thickness in certain localities, and its continuity in the Lowlands, furnishes impressive testimony of the modification of the country during the period of maximum extension of the ice; but though the area which it covers on the mainland seems large, it is in reality small compared with the covering which must have been spread over the Continental Shelf.

During the retreat of the great *mer de glace*, marginal lakes were formed between the ice-front and the slopes of the hills from which the ice had melted away, thus giving rise to terraces of sand and gravel, at a height in some cases of several hundred feet above the present level of the sea. Typical examples of such phenomena, resulting in the modification of the drainage of the country, have been described by Professor James Geikie as occurring on the slopes of the Eaglesham and Strathavon Hills, and by Professor Kendall and Mr Bailey on the northern declivity of the Lammermuir Hills.

At certain localities in Scotland, as for instance at Clava, near Inverness, and on the west coast of Kintyre north of Machrihanish, deposits of clay with arctic shells are found beneath boulder clay, which differ in character and origin from the shelly boulder clay of Caithness, Orkney, Ayrshire, and Wigtownshire. The shelly clays at the former localities are marine deposits, which indicate a depression of the land before the maximum extension of the ice, while the shelly boulder clays have been formed by land ice, which in its onward march had previously passed over a portion of a sea floor.

LATER GLACIATION

During the later glaciation the centres of ice dispersion were wholly changed. Instead of three great areas of distribution on the mainland, each mountain group seems to have nourished its own system of glaciers. It is true that for a time the glaciers became confluent, and that the ice passed over intervening cols from one line of drainage to another. But as a rule the direction of the ice-flow coincided with the trend of the valley system. Thus we find that in certain areas the ice moved in a direction precisely opposite or oblique to that during the continental ice-phase. A change so marked seems to afford reasonable ground for maintaining that these glacial epochs may have been separated by an inter-glacial period.

The phenomena characteristic of the later glaciation are typically developed in the Highlands. All the main valleys were filled with trunk glaciers fed by innumerable tributaries draining the various mountain groups. In the tract lying to the north-west of the Great Glen the glaciers seem to have reached the sea-level in nearly all the firths of the East Coast, and in nearly all the sea-lochs and sounds on the western seaboard. On the north shore of Sutherland the ice apparently moved out to sea, and formed a more or less continuous ice-front extending from the borders of Caithness westwards as far as the Kyle of Tongue, while lobes of ice occupied Loch Eireboll and the Kyle of Durness. What may be conveniently described as ice-cauldrons were set up in Central Sutherland, and in the district of Loch Monar on the borders of Ross-shire and Inverness-shire.

Even the remote Orkney and Shetland Isles, and the hills of Lewis and Harris in the Outer Hebrides, nourished their own independent glaciers.

In the region situated between the Great Glen and the Midland Valley, glaciers occupied the main valleys, and formed in certain areas lobes of ice on the plain. They reached the sea-level in most of the western fjords, but not on the East Coast. An ice-cauldron was established on Rannoch Moor—an area surrounded by lofty mountains—which was drained by a few principal gaps.

In the Southern Uplands there was only a limited development of valley glaciers. In the Lammermuir Hills and the Moorfoots no deposits characteristic of this period have been detected. Westwards we find evidence of small ice-streams in the valleys draining Broadlaw, Hartfell, and Ettrick Pen, the Lowther and Queensberry Hills, and the mass of high ground culminating in Cairnsmore of Carsphairn, between Sanquhar and the sources of the river Ken. The great cauldron between the Kells and Merrick ranges was so thickly filled with ice that glaciers issued from all the main gaps, bearing granite boulders for a considerable distance from their parent source. The greatest confluent glacier of this period in the Southern Uplands was formed by the ice that issued from the central cauldron by Glen Trool, which, uniting with the Minnock glacier, fed by various tributaries on the western declivity of the Merrick range, spread far over the plain.

There is a marked difference between the conditions of erosion of the continental ice-sheet and those of the valley glaciers. During the former phase, as already indicated, the ice-shed was largely independent of the existing watershed, and the movement was frequently across the valleys. No rock debris could fall on to the surface of the *mer de glace* on the mainland, and the main escape of the melt-water was beyond the limits of the present land surface. During the later phase the glaciers mostly radiated from the main mountain groups and followed the trend of the valleys. At the same time the prominent crags furnished materials which were borne downwards to lower levels on the surface of the ice. The glaciers interrupted the drainage of bare areas and thus received a supply of water, which doubtless raised the temperature of the ice to the critical melting-point relative to pressure, thus ensuring more rapid flow. This water, combined with that set free from the ice, often under great hydrostatic pressure, must have circulated on the floor in hollows below water-level, thereby abstracting the "flour of rock," increasing the erosive action of the ice. These phenomena show that during the later glaciation ice-erosion was mainly concentrated on the valley floors, which would tend to over-deepen the main valleys and produce rock-basins in them.

The glacial accumulations characteristic of this period are well defined. Where the great valley glaciers debouched on the plains,

MAP SHOWING DIRECTION OF ICE FLOW AND PROBABLE ICE FRONT IN NORTH-WEST EUROPE DURING MAXIMUM GLACIATION.

The Edinburgh Geographical Institute

J.G. Bartholomew.

concentric ridges of gravel and morainic material indicate their lower limits. Within the valleys the hill-slopes are terraced with lateral moraines, and the floors are strewn with mounds and ridges, often of horseshoe shape, marking stages in the farther retreat of the ice. That old wind-gaps between adjoining ridges were used as overflow channels is shown by the occurrence of gravels at these levels where only dry hollows now exist, and by the occurrence of rock notches across comparatively steep slopes. These phenomena, which are of common occurrence in certain districts of the Highlands, point to temporary drainage deflected by the ice, which continued long enough to enable the streams to entrench themselves. Sometimes lakes of considerable extent were impounded by ice-barriers, as in the case of the Parallel Roads of Glen Roy, where each terrace marks the temporary margin of a lake the height of which is determined by the level of the lowest col free from ice. Another characteristic feature of this period of retreat of the glaciers is the deposition of a series of fluvio-glacial gravels due to the escape of melt-water, which led to the reassortment of the morainic material, sometimes round masses of ice isolated from the retreating glaciers.

The last phase of the later glaciation was characterised by the occurrence of small glaciers in the high corries, which sometimes gave rise to small rock-basins, terminal moraines, and groups of mounds. In the North-West Highlands these local glaciers survived to a late period in the geological history of the country, as they rest on the deposits of the 50-ft. beach at the head of Loch Torridon.

The Distribution and Probable Origin of Scottish Lakes

The numerous lakes in Scotland, ranging in size from small tarns on the high plateaux and pools on the drift plains to large sheets of water in the valleys, may be arranged in the following groups:—

i. Lochans lying in hollows in, or surrounded by, peat.

ii. Lakes due to the action of the wind: (1) by the interruption of drainage in the case of sand-dunes, as, for instance, Loch Strathbeg near Fraserburgh, Loch Wester in Caithness, and numerous lakes on the west side of South Uist; (2) by the removal of disintegrated rock, as, for example, on high granite plateaux.

iii. Lakes due to river action: (1) those formed on flat cols by cones of debris, of which Loch na Bi, near Tyndrum, is an instance; (2) crescent-shaped or "oxbow" lakes resulting from the isolation of stream-meanders on flood-plains.

iv. Lakes due to wave action on the seashore, where sheets of water are enclosed by gravel bars (Loch Sine, on the west side of Loch Eireboll).

v. Lakes caused by chemical action on limestone plateaux (Loch Borralaidh and Loch Croisaphull near Durness, Loch Maol a' Choire or the Gillaroo Loch near Inchnadamff).

vi. Lakes resulting from the irregular distribution of the drift: (1) those lying in boulder clay; (2) those resting on morainic deposits; (3) those situated partly on drift and partly on solid rock; (4) kettle-holes caused by the accumulation of fluvio-glacial sand and gravel round isolated masses of ice during retreat.

vii. Lakes occupying rock-basins, which may be thus classified: (1) plateau rock-basins, (2) valley rock-basins, (3) corrie rock-basins, (4) those lying along shatter belts due to faults.

By far the largest number of Scottish lakes is included under the last two groups of the above table. There is little room for controversy regarding the origin of the various lakes in Scotland, except those lying in true rock-basins. We will now proceed to consider the probable origin of the latter series in the light of the evidence which has already been presented regarding the geological structure, the topography, and the glaciation of the country, with the aid of the fresh data obtained by the Lake Survey.

PLATEAU ROCK-BASINS

The plateau basins are extremely abundant in the coastal belt occupied by the Lewisian gneiss on the western seaboard of Sutherland and Ross, and also in the Outer Hebrides, where the rocks are remarkably bare of drift. They may, however, occur at any elevation. Contrasted with the valley rock-basins they are comparatively small and shallow. Their distribution is very irregular, and altogether independent of drainage. The soundings show that their floors are uneven, and that in some cases, as in the Outer Hebrides, four or five separate basins occur in one lake.

To account for them by differential movement would not only necessitate a special subsidence in each case, but several irregular movements for each lake containing several distinct basins. It is no doubt true, as described in the section relating to geological structure, that the Lewisian rocks are traversed by shear planes and disruption lines which modified the structures of these rocks in pre-Torridonian time; but such movements cannot possibly account for these shallow, irregular depressions. This theory seems to us so improbable as to be quite untenable.

On the other hand, evidence has been adduced in the section dealing with glaciation to show that this coastal belt was crossed by an ice-sheet that filled the Minch and overtopped the Outer Hebrides, whose thickness could not have been less than several thousand feet. Throughout the Lewisian Gneiss plateau there are clear proofs of the moulding of the surface features by glacial action, and of the differential erosion of the rocks by ice. The lake soundings show that weak structures have there undergone the greatest modification, which may be reasonably attributed to the action of this agent. In view of this evidence, the phenomena presented by these plateau basins may be satisfactorily explained by the action of land ice.

VALLEY ROCK-BASINS

Valley rock-basins are more important topographical features, and the question of their origin has excited keener controversy. One condition of prime importance in the formation of such basins is the production of graded valley floors, reduced to a base-level either with regard to the sea or to barriers of hard rock with intervening weaker strata. These flat reaches might then be converted into rock-basins either by differential crustal movements with or without lateral compression, or by land ice, which is capable of eroding below the action of running water, as suggested by Sir A. C. Ramsay. It need hardly be pointed out that aqueous erosion is incapable of producing the characteristic phenomena of valley rock-basins.

The soundings of the Lake Survey have established certain points which are highly suggestive in connection with the question of the origin of such basins. They show (1) that these depressions are U-shaped in cross-section, like the contour of the glaciated valleys in which they lie; (2) that there is a lack of adjustment between the large valley rock-basins and tributary streams, the relation between them being analogous to that between trunk streams and tributary hanging valleys; (3) that while the large lakes have usually comparatively flat floors, many of them have several distinct basins; (4) that the deepest soundings frequently occur where the constriction of the valley is greatest; (5) that the steepest slopes are often found at concave bends in the larger rock-basins, where it can be shown that the differential erosion of the ice must have been most powerful.

All these phenomena indicate that valley rock-basins present many of the features which are characteristic of glacial action. But in addition to these points we will now proceed to show that the distribution and form of many of the rock-basins in Scotland are produced under complex local conditions dependent on the geological structure, pre-glacial topography, and differential ice-erosion of the particular regions in which they occur.

A study of an orographical map of Scotland shows that valley rock-basins are almost confined to those highly dissected regions where deep through valleys have been established between high mountains, and where the cols form low divides or passes in the existing watershed of the country. In the section dealing with topography we have endeavoured to point out that the westerly and northerly flowing streams have, by capture, reversed the drainage and produced a series of through valleys. Such features are specially developed in the western portions of the Northern, Central, and Southern

Blocks into which the country is divided. The evidence bearing on the glaciation of these areas clearly indicates that these depressions acted as outlets for a larger volume of ice than could have been obtained from the catchment basin of the valley containing a particular rock-basin. In the Northern Block, where during the maximum glaciation the ice-shed lay to the east of the existing watershed, these conditions must have had a marked influence on the direction and volume of the ice-flow. In the western part of the counties of Sutherland and Ross, Lochs More, Stack, Veyatie, Lurgan, Loch na Sheallag, and Loch Fada may be quoted as examples of lakes that originated under these conditions. Loch Maree is similarly situated, and some of the sea-lochs in that region are true fjord basins. In North Sutherland, where deep through valleys draining northward from the central plateau have been established, similar rock-basins are to be found, as, for instance, Loch Hope, Loch an Dithreibh, Loch Laoghal, Loch Naver, and Loch Coir' an Fheàrna.

It is a remarkable fact that rock-basins are extremely rare in the Monadhliath and Cairngorm Mountains, and the Eastern Grampians, where there are extensive areas of undissected plateau. In these regions the valleys are open and comparatively shallow; they have an almost uninterrupted slope, and they lead up to lofty ground. A similar contrast is observable in the Southern Uplands; for in the Moorfoot and Lammermuir Hills in the eastern part of that tableland, lakes occupying rock-basins have not been recorded, while far to the west among the high grounds of Galloway they are prominently developed. It will be shown in the sequel that the Galloway rock-basins are dependent upon the remarkable topographical features of that region which resulted in extreme differential erosion during both periods of glaciation.

The distribution of many of the Scottish rock-basins further shows that individual lakes and even groups of lakes are ponded by rocky barriers that form prominent features in the geological structure of the country. A remarkable series illustrating these characteristics, and comprising, among others, Loch Katrine, Loch Ard, Loch Chon, Loch Lubnaig, Loch Voil, and Loch Earn, and the upper part of Loch Lomond, occurs on the border of the Eastern Highlands in Perthshire.[1] In that region the rocky barrier consists chiefly of metamorphic schistose grits (the Ben Ledi and Leny grits) trending in an east-north-east and west-south-west direction, which are followed inland by weaker strata composed of phyllites and mica-schists. Loch Katrine may be taken as the most striking example of the group, as it displays in a remarkable manner certain features which, in our opinion, point to differential erosion by ice. In the geological notes

[1] See Appendix.

descriptive of this lake we have stated that for a distance of four miles west from Brenachoil Lodge to Stronachlachar—about half of the total length of the loch—the lake has a comparatively flat bottom enclosed by the 400-feet contour line. The deepest sounding is 495 feet, which is situated at the eastern limit of this basin, nearly due south of Brenachoil; and the chart shows that the soundings gradually increase in depth eastward to Brenachoil. The position of the deepest sounding is of special interest; for the strata which there occupy the floor of the lake consist of schistose micaceous grits in front of the massive Ben Ledi grits and epidotic grits (Green Beds) which form the great rocky barrier at and above the outlet of the lake.

A study of an orographical map shows that the depressions containing these lakes are connected by low passes with valleys lying farther to the north; and hence, during the period of confluent glaciers, the volume of ice would be greatly increased and maintained for a considerable time.

Another series of valley rock-basins illustrating the relation of geological structure to differential ice-erosion occurs in the North-West Highlands, where the lakes lie in weaker Torridonian strata and the barrier consists of the harder Lewisian Gneiss. In the Coigach district of West Ross-shire a chain of lakes—viz. Lochs Bad a Ghaill, Rudha na h'Aclise, and Lurgain—is ponded by a ridge of Lewisian Gneiss once deeply buried beneath the Torridon Sandstone till the denuding agents that formed the valley exposed its top. Loch a' Bhealaich and Loch Damh, on the north and south sides of Loch Torridon respectively, lie in Torridonian strata with a similar barrier of Lewisian Gneiss. The sea-lochs Little Loch Broom and Upper Loch Torridon, which are small fjord basins, fall into the same category.

Loch Shin is an excellent example of a lake ponded by a rocky barrier. It lies more or less along the strike of the crystalline schists of the Moine series in the old consequent valley of the Shin, and its barrier consists of a belt of the same rocks invaded and indurated by a plexus of granite intrusions which have rendered them highly resistant.

No less striking instances are those elongated rock-basins in the valleys of Coruisk (Loch Coruisk) and Camasunary (Loch na Creubh-aich) in Skye, which have been fully described by Mr Harker. The determining condition in both cases was the same, a marked constriction of the valley towards its lower end, which must have occasioned a heaping up of the ice. Mr Harker states that in Coruisk the constriction was caused by the Sgùr Dubh ridge running out eastward from the main range; while in the Camasunary valley the same effect was produced by the convergence southward of the flanking ridges Blathbheinn on the east, and Druim an Eidhne, Sgùrr an Eidhne, and Sgùrr na Stri on the west.

Among Scottish rock-basins, perhaps the most convincing examples of the relation of differential ice-erosion to topography are those that radiate from what may be described as ice-cauldrons. The first group to which attention may be directed occurs in the mountainous district of Galloway, where a cauldron-like hollow representing a drainage area of sixty square miles is situated between the Kells and Merrick ranges of hills. The hollow is due to the differential weathering of the granite mass extending from Loch Doon to Loch Dee and its surrounding aureole of altered Silurian sediments which have been indurated by contact metamorphism with the granite. The lofty hill ranges bounding the central granite mass are composed of these altered sediments, and these are breached by the rivers Doon, Dee, Girvan, and the Trool, a tributary of the river Cree.

The Doon, an obsequent stream in a through consequent valley still partly drained by the consequent Dee, has base-levelled a large part of the interior granite mass, and has formed a watershed with the Dee in a deep valley, upon a low flat col studded with lochans. The Trool though breaching the barrier at a lower level than the other streams, has not been able to remove so much of the interior granite, and hence drains a higher part of the plateau. The river Girvan enters the cauldron on a higher level than the Doon, and has therefore been beheaded by tributaries of the latter stream. Hence by the action of these streams the granitic detritus has been removed at a quicker rate than the debris of the altered Silurian sediments. Loch Doon, the chief outlet, drains nearly two-thirds of the central plateau, while the remainder of the catchment basin is about equally shared by the Dee and the Trool, the part drained by the Girvan being extremely small.

In the description of the glaciation of the Southern Uplands we pointed out that this mass of high ground formed an axis of dispersion during both periods of ice extension, when a large reservoir of ice must have accumulated in the central cauldron, which discharged deep streams by the respective gaps.

Loch Doon, occupying the floor of the largest gap, has been described as a typical rock-basin showing clear traces of glaciation round its shores, on its rocky islets, and at its outlet, where well-striated *roches moutonnées* appear. The deepest sounding (100 feet) occurs where the valley is constricted by the northern range of altered Silurian sediments abutting against the loch east of the Wee Hill of Craigmullach. Below this point the lake widens, and its floor there forms a shallower basin, where it emerges from the higher hills on to the lower ground. The barrier at its outlet consists of massive gritty greywackes belonging to the Silurian system.

Loch Dee is situated near the south-eastern gap, and partakes of the character of a plateau basin and of a valley rock-basin; for there must have been a considerable escape of ice by the col at the head of the Black Laggan valley, though the drainage of that stream is northward towards the cauldron. The long narrow peat-moss traversed by the Cooran Lane to the north of Loch Dee probably conceals a silted-up valley rock-basin.

Loch Trool, occupying the south-western gap, is a typical rock-basin excavated along the strike of the altered Silurian strata. The deepest sounding (55 feet) occurs near the head of the lake, where the valley is most constricted; and the basin gradually shallows where it enters the low ground of Wigtownshire. As in the case of Loch Doon, there is here clear evidence of differential ice-erosion on the shores and rocky islets of the lake.

Loch Girvan Eye, at the head of the river Girvan, is a small rocky tarn evidently due to ice-erosion. Several plateau rock-basins occur on the floor of the central cauldron, as for instance Lochs Macaterick, Lochricawr, and Enoch, which drain into the Doon, and Lochs Neldricken and Valley, which discharge into the Trool. The last of these is ponded by moraines, but the granite is exposed not far below the outlet.

Rannoch Moor, embracing an area of about 180 square miles, also appears to have acted as an ice-cauldron, radiating ice through gaps in the surrounding high ground. It now forms a plateau with a general height of about 1000 feet, composed mainly of granite, with encircling mountains rising to a height of over 3000 feet, consisting chiefly of crystalline schists of sedimentary origin. Several lines of fault or shatter belts traverse the granite and surrounding schists in a north-east and south-west direction. Situated about the middle of the Central Block, it is drained by streams that have breached the mountain barriers and have base-levelled large areas of the Moor. The river Tummel—a tributary of the Tay—has accomplished more work in this direction than any of the other streams. The geological history of the Rannoch plateau closely resembles that of the Galloway cauldron just described. From its situation also it served as a reservoir for the accumulation of ice during both glaciations.

It is a remarkable fact that rock-basins are situated in many of these gaps, where the volume of ice issuing from the central cauldron would be greatest and its erosive power, subject to local conditions, would be increased. Loch Rannoch, situated in the widest gap, is a fine example of a rock-basin; for though at the lower end the river Tummel on issuing from the lake flows along an alluvial flat for a distance of three miles as far as Dun Alastair, a rocky barrier appears at the latter point in the river and on the hill-slopes. This barrier culminates in Schichallion (3547 feet) and Beinn a' Chuallaich (2925 feet) on either side of the valley. The ice moved down the valley from the Rannoch Moor, and it is worthy of note that the deepest sounding (440 feet) occurs in the centre of the largest and most easterly of the three small basins between the mouth of the Dall Burn and the foot of the loch, the locality being within two miles of Kinloch Rannoch. Farther down the same depression, Loch Tummel furnishes another instance of a rock-basin, the rocky barrier appearing in the stream and on the hill-slopes at Allean House, about a mile below the mouth of the lake.

Loch Ericht, along a line of shatter belt, is situated in one of the outlets from the Rannoch cauldron. The loch forms a simple basin, which is deepest where the valley is most constricted, and it shallows as it approaches the wider valley of the Spey. Loch Ossian—a true rock-basin—occurs in another gap, and likewise Loch Treig, which runs along a line of fault. The latter is a simple rock-basin, and, like many of the other lochs, is deepest where the constriction is greatest. A chain of small rock-basins occurs in the Leven valley, and another instance (Loch Triochatan) is to be found in Glencoe. Loch Tulla, located near the outlet of several through valleys, presents features characteristic of the plateau type and of the valley type of rock-basin.

A small ice-cauldron is situated in the Monar region on the borders of Ross-shire and Inverness-shire, whose floor is about 700 feet above sea-level, while the surrounding mountains rise to above 3000 feet. The only valley issuing from this central area is Glen Strath Farrar, at the head of which lies Loch Monar, a true rock-basin. In our notes descriptive of this basin (see Vol. II. Part I. p. 351) we have pointed out that the ice radiating from this cauldron during the period of confluent glaciers flowed eastward down Glen Strath Farrar, and streamed northward through some of the passes towards the Orrin and Glen Fhiodhaig, and westward in the direction of the valley of the Ling. At a later stage it escaped only by Strath Farrar. The rocks forming the barrier of Loch Monar are well seen in the gorge of Garbh-uisge, about half a mile below its present outlet, where they consist of massive siliceous Moine schists plicated along vertical axes trending north-east and south-west. Loch Calavie—a small rock-basin—is situated on one of the passes leading towards the Ling valley, and other rocky tarns are to be found near the low cols separating the Monar basin from the Meig and the Orrin.

A series of valley rock-basins, comprising Lochs Arkaig, Garry, Loyne, Clunie, Affric, Beinn a' Mheadhoin, Mullardoch, and Bunacharan, occur in the Northern Block where the rivers leave the high plateau and debouch on the Great Glen, or on the intermediate plateau and coastal plain of the Beauly Firth. It is worthy of note that each of these lakes occupies the same relative position in each valley, where the trunk glacier had received its main accessions of ice from the tributary glens and before it proceeded to fan out.

Another group of valley rock-basins occurs in Easter Ross. In the central portion of that county, the River Bran and the Black Water, tributaries of the Conon River, drain a low plateau occupied by granulitic Moine schist and augen gneiss, which is bounded on the east by more elevated ground extending from Sgùrr a' Mhuilinn north-eastward to Ben Wyvis, composed of muscovite-biotite gneiss. During the period of confluent glaciers, the central low plateau acted as a reservoir of ice, part of which passed outwards through the main gaps in which Loch Luichart and Loch Garve are situated. Another portion was deflected northward by Ben Wyvis, and moved down the valley of the Glass, in which lies Loch Glass.

CORRIE ROCK-BASINS

Corrie rock-basins are of minor importance, for they are invariably small and shallow and confined to mountainous regions. They occupy the floors of cirques or corries, with rocky barriers in front and with prominent cliffs of rock behind them. Round the lip of each tarn there is clear evidence of differential erosion by ice under extreme pressure due to the downward movement of the mass. Sometimes the rocky barriers are concealed by moraines deposited by the corrie glaciers.

On the northern declivity of the Ben More range in Assynt, Sutherlandshire, there are excellent examples of corrie rock-basins. For instance, Loch a' Choire Dearg and Loch a' Choire Ghuirm are situated at a height of about 1750 feet on the north shoulder of Glas Bheinn (2341 feet), and lie on a glaciated floor of Lewisian gneiss, while the walls of the cirque are composed of Cambrian quartzite. Several additional examples occur along the base of the escarpment of Cambrian quartzite extending eastwards to Ben More, the finest being the tarn at the head of Coire Mhadaidh Bheag at a height of 2500 feet. The glaciated floor of this rock-basin is composed of Torridonian and Lewisian rocks partly encircled by cliffs of Torridon Sandstone and Cambrian quartzite.

Loch Toll an Lochainn is one of the best examples of this type of basin in the North-West Highlands. It occurs at a height of 1700 feet in the An Teallach range, Ross-shire. The lake is floored by well-glaciated Torridon Sandstone, and is surrounded on three sides by cliffs of massive grit belonging to the same formation. Again, in the hollow between Sgùrr na Lapaich (3775 feet) and Riabhachan

(3696 feet) on the confines of Ross-shire and Inverness-shire, two instances occur in a double corrie at a height of 2250 feet. They lie on a well-glaciated floor of hornblendic gneiss with prominent cliffs of muscovite-biotite gneiss rising behind them.

Mr Harker has noted the occurrence of the following corrie rock-basins in the Cuillins:—Coir' a' Bhasteir at an altitude of 2250 feet; Coir' a' Ghrunnda, 2220 feet; Coir' an Lochain, 1815 feet; Coire Labain, 1805 feet, which he ascribes to excessive ice-erosion in the head portions of the valleys.

ROCK-BASINS ALONG SHATTER BELTS

Reference has already been made to many rock-basins lying along lines of fault or shatter belts. The soundings of the Lake Survey show that, as a rule, they form simple basins with comparatively flat floors, and U-shaped in cross-section. Like the valley rock-basins free from shatter belts, they are an integral portion of the valley system in which they occur. The members of this group are of most common occurrence in the highly dissected plateaux where the normal valley and plateau basins are most abundant. In all those regions where valley rock-basins are absent the shatter belts are hollowed out relatively to the trunk streams which cross them.

Loch Ness is perhaps one of the best examples of this group, for it lies along the line of fault traversing the Great Glen. It is ponded partly by glacial deposits and fluvio-glacial gravels, and partly by raised beaches; but as it is deeper than any part of the bed of the North Sea between Scotland and the Norwegian Deep, there can be little doubt that it is a rock-basin. The soundings show that it possesses the typical form of a rock-basin. Like other depressions, it received great accessions of ice from either side, and was subjected to extreme erosion by the ice moving north-eastward towards the Moray Firth.

In brief, a careful consideration of all the available evidence has led us to the conclusion that the distribution and form of Scottish rock-basins bear a direct relation to the geological structure, topography, and glaciation of the particular regions in which they occur, and that such basins merely represent a phase of the differential erosion of the whole country by the action of land ice.

In the preparation of this paper and of the notes descriptive of the geological features of the rock-basins, we have freely availed ourselves of the information embodied in the maps and memoirs of the Geological Survey of Scotland. We desire further to acknowledge our obligations to the officers of the Geological Survey for valuable assistance rendered during the progress of the Scottish Lake Research investigations.

In addition to the publications of the Geological Survey of Scotland, the more important works which have been consulted in the preparation of this paper are given in the subjoined list.

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Note.—The admirable orographical maps published by J. Bartholomew, Edinburgh, have been of the greatest service to us in studying the evolution of Scottish topography.

APPENDIX

GEOLOGICAL NOTES ON SCOTTISH LOCHS SOUNDED BY THE LAKE SURVEY

ABOYNE.—Loch ponded by drift.

ACHALL.—Valley rock-basin in Moine schists, piled up Lewisian Gneiss, and Torridonian strata below Moine thrust-plane.

ACHANALT.—Vol. II. Part I. p. 289.*

ACHILTY.—Vol. II. Part I. p. 290.

ACHLAISE, NA H-.—Shallow loch ponded by drift lying on moraine-strewn surface of schist and granite.

ACHRAY.—Vol. II. Part I. p. 48.

AFFRIC.—Valley rock-basin in granulitic schist; with two deltas at Affric Lodge.

AILSH.—Vol. II. Part I. p. 307.

AIRIDH NA CEARDAICH.—Irregular rock-basin in Lewisian Gneiss.

AIRIDH NA LIC.—Hollow in Lewisian Gneiss, probably ponded by drift.

AIRIDH SLÉIBHE, NA H-.—Rock-basin in Lewisian Gneiss.

AITHNESS.—Rock-basin in altered Old Red Sandstone and intrusive igneous rocks, partly drift-dammed.

ALLAN.—Hollow among moraines.

ALLT AN FHEÀRNA.—Hollow in morainic material resting on Moine schists.

ALLT NA H-AIRBHE.—Rock-basin in Lewisian Gneiss.

ALVIE.—Kettle-hole in fluvio-glacial deposits.

ANNA.—Rock-basin in Lewisian Gneiss.

ARAICH-LIN.—Drift-dammed loch resting on crystalline schists.

ARD.—Vol. II. Part I. p. 51.

ARIENAS.—Rock-basin in crystalline schists at foot of escarpment of Tertiary volcanic rocks overlying Cretaceous strata; probably determined by the line of fault that truncates the south-eastern end of the Morvern plateau.

ARKAIG.—Simple valley rock-basin in crystalline schists and granite.

ARKLET.—Vol. II. Part I. p. 49.

ARTHUR.—Small rock-basin near edge of Criffel granite massif, partly ponded by drift.

ASHIE.—Vol. II. Part I. p. 431.

ASLAICH.—Small, narrow drift-dammed loch in schists.

ASSYNT.—Vol. II. Part I. p. 187.

ASTA.—Rock-basin along strike of crystalline schists and metamorphic limestone; may be in part due to solution. One of the Tingwall lochs, Shetland.

AUCHENREOCH.—Drift-dammed loch.

* Volume II. contains geological notes on those lakes not described in this Appendix, the reference being given here in each case.

Aùscot, nan.—Rock-basin in Lewisian Gneiss.

Avich.—Rock-basin in quartzites, phyllites, limestones, and epidiorites (Loch Awe group). Like Loch Awe, the upper end of this loch is in part surrounded by a high terrace of sand and silt 200 feet above the present surface of the lake, which must have been formed when the rest of the rock-basin was occupied by a lobe of ice projecting from the Loch Awe glacier. The height of this terrace was determined by the level of the col at the head of the valley over which the loch must have drained westwards into the Barbreck river towards Loch Craignish.

Awe (Etive basin).—Valley rock-basin, mostly along the strike of crystalline schists, composed of altered sedimentary and igneous rocks (Loch Awe group), and partly along the shatter-belt of the Pass of Brander fault, in consequence of which the loch forks. The lake has two basins. The more southerly and longer one from Ford to the island of Inistrynich follows the strike of the strata, while the other coincides for some distance with the Pass of Brander shatter-belt and then bends nearly at a right angle towards the mouth of the river Orchy. The two basins are separated from each other by a comparatively shallow plateau, on which the rocky islands are situated. The study of the glaciation of the region shows that, during the confluent glacier period, the Pass of Brander, although of pre-glacial origin, was not sufficiently wide to drain off all the ice poured into the head of Loch Awe by the convergent glens of the Shira, the Orchy, and the Lochy. From the soundings of the Lake Survey it may be inferred that the ice that passed through the Pass of Brander worked along the comparatively weak belt of shattered rock in the pass, thus producing the peculiar L-shaped basin shown in the charts. The surplus ice streamed across the shallow plateau, and, gaining accessions from the Ben Lui and Ben Buidhe mountain masses, moved towards the south-west end of the lake. As the valley narrowed, the abrading action of the ice was increased, which resulted in the longer and deeper basin along the strike of the strata. The phenomena at the south-west end of the loch show that, at a period during the retreat of this confluent glacier, the Craig an Tairbh pass was choked by the ice, and the melt-water of the glacier escaped across a high col into the river Add above Kirkmichael Glassary. Thereafter it streamed through an intermediate gap into the Add by the lower end of the Kilmartin valley; and subsequently, when the ice had farther retreated, by the Craig an Tairbh pass itself into the same valley above Kilmartin. During the recession a lobe of ice became detached and occupied the site of Loch Ederline, and was there surrounded by the fluvio-glacial gravels from the melt-water of the glacier. A still farther retreat of the glacier left a lake occupying the south-west part of the existing Loch Awe, the level of which was determined by the height of the Craig an Tairbh pass, where the rocks still retain the pot-holes eroded by the old glacial stream. The continued recession of the ice was slow enough to allow a terrace of beach and delta material to accumulate along the ice-dammed lake. Subsequently, when the Pass of Brander was free from ice, the lake assumed a form approaching the present outlines. Since glacial time the upper part of the northerly rock-basin has been much silted up with the alluvia of the converging streams, and small delta lakes are being formed by the advancing sediment. The contours at the upper end of the loch show that the slope there is that of an advancing delta.

Awe (Inver basin).—Shallow basin ponded by drift with morainic debris on Cambrian quartzite and *Olenellus* beds.

Bà (Mull).—A valley rock-basin in granophyre, intrusive into igneous rocks of the Tertiary volcanic plateau in Mull. The lines of fissure followed by the great series of basalt dykes which traverse the plateau, seem to have determined the direction of the valley, and consequently the trend of the lake. Its water-level is raised by a dam consisting of raised-beach material.

Bà (Tay basin).—Shallow, drift-dammed loch lying on moraine-strewn surface of the granite mass of Rannoch Moor, the moraines forming numerous islands and headlands.

Bad a' Chròtha.—Rock-basin in Torridon Sandstone nearly silted up.

Bad a' Ghaill.—Vol. II. Part I. p. 190.

Bad an Sgalaig.—Rock-basin in Lewisian Gneiss.

Baddanloch.—Drift-dammed shallow loch in wide valley carved out of granulitic quartz-biotite schists and muscovite-biotite gneiss and granite veins.

Baile a' Ghobhainn.—Rock-basin in limestone and black schist due partly to ice action and partly to solution. The limestone overlies the black schist or slate, which acts as the retentive layer and forms the bed of the loch along the line of an eroded anticline; the surface of the water determining the line of saturation of the limestone which occupies the synclinal folds (see Loch Fiart).

Balgavies.—Lake ponded by drift upon Lower Old Red Sandstone strata.

Beag.—Part of the same valley rock-basin as Loch Clunie.

Beannach (Gruinard basin).—Fills hollows among moraines resting on Lewisian Gneiss.

Beannach (Inver basin).—Rock-basin in Lewisian Gneiss, so called from the numerous islands (*roches moutonnées*) with which it is studded.

Beannachan.—Vol. II. Part I. p. 289.

Beinn a' Mheadhoin.—Valley rock-basin connected with Loch an Laghair.

Beinne Bàine, na.—Lake lying partly in crystalline schist and partly in drift, situated on watershed.

Beiste, na.—Small hollow in boulder clay resting on Torridon Sandstone.

Beithe, na.—Kettle-hole in 100-ft. raised beach.

Benisval.—Rock-basin in Lewisian Gneiss.

Beoraid.—Valley rock-basin in granulitic schists and muscovite-biotite gneiss in valley drained by the river Meoble, along which ice flowed from the head of Loch Eil into Loch Morar.

Bhaid Daraich, a'.—Hollow in Lewisian Gneiss, the barrier consisting in part of raised-beach material. It is probable that the bed of the loch is a rock-basin which was occupied by ice during the deposition of the beach.

Bhaid Luachraich, a'.—Irregular rock-basin in Torridon Sandstone, partly ponded by drift.

Bhaillidh, a'.—Minor rock-basin studded with moraines on the course of the Leven, now covered by the water of the great dam for the Leven Power Works.

Bhainne, a'.—Lochan in schist ponded by drift.

Bharpa, a'.—Rock-basin in Lewisian Gneiss.

Bhealaich, a' (Alsh basin), or Loch of the Pass.—Rock-basin in granulitic schists on pass at head of the Glomag—practically on the watershed between Strath Affric and the Elchaig, over which ice streamed from the east during the maximum glaciation and the subsequent confluent glacier stage. It is one of a series which almost invariably occur where ice has passed over a low watershed in a through valley.

Bhealaich, a' (Gairloch basin).—Rock-basin situated in valley, open at both ends. The lower end of the loch lies upon the Lewisian Gneiss, while the upper end is bounded on both sides by the overlying Torridon Sandstone. The valley throughout the greater part of the glacial period acted as an outlet for a greater volume of ice than could have been obtained from its own catchment basin, and the basin occurs just where the ice must have been most constricted.

Bhealaich, a' (Naver basin).—Rock-basin in granulitic schists. Situated in valley open at both ends, which became one of the outlets for the ice radiating from the cauldron of Central Sutherland during the maximum and confluent glacier stages of the glacial period. It is merely the upper portion of Loch Coir' an Fheàrna.

Bhradain.—Rock-basin in Moine schist.

Bhraoin, a'—Rock-basin in granulitic quartz-biotite schists, in part determined by the line of shatter-belt of the Fasagh fault.

Bhuird, a'.—Rock-basin in Lewisian Gneiss.

Bì, na.—Lies on an open pass on the watershed of Scotland, where the Lochy, a tributary of the Orchy, had appropriated the head-waters of a branch of the Tay, and through which ice from the Tay valley passed over into Loch Awe, thus lowering the col. The loch lies on morainic material, and is ponded by the deltas of the small side-streams which the outflow is unable to remove, the gradient being too gentle.

Birka.—Small rock-basin on granite of Roeness Hill, Shetland.

Black (Etive basin).—Chain of small rock-basins in the volcanic rocks of the Lorne plateau. The valley in which they lie was evidently an arm of the sea during the stage of the 100-ft. beach, since a fringe of that beach is traceable at intervals round the lakes. Fluvio-glacial deposits, due to melt-water from the lobe of ice which passed down the Lonan valley into Loch Nell, occur along the western end of the chain of lakes.

Black (Ryan basin).—Kettle-hole in fluvio-glacial gravels of 100-ft. beach; has been continuous with the White Loch, from which it is now disjoined by the delta of Sheuchan Burn.

Black (Tay basin).—Kettle-hole on pass between Lindores and the Howe of Fife.

Blairs.—Kettle-hole in fluvio-glacial deposits.

Boardhouse.—Hollow in flagstones of Middle Old Red Sandstone age, ponded by drift.

Bodavat.—Rock-basin in Lewisian Gneiss.

Bogton.—Partly a rock-basin in Coal Measures, and partly drift-dammed; now much silted up by the river Doon, which flows through it.

Borralan.—Vol. II. Part I. p. 191.

Bosquoy.—Resting on Middle Old Red flagstones, and ponded by drift.

Bradan.—Drift-dammed lake lying on Lower Silurian greywackes and shales.

Braigh Horrisdale.—Rock-basin partly in Lewisian Gneiss and partly in Torridonian rocks.

Bran.—One of a group of small rock-basins on a floor of Old Red Sandstone and crystalline schists along the south-east side of Loch Ness. At Loch Bran the platform is cut in schists from 600 to 700 feet above the level of Loch Ness. The streams draining these lochs, of which the Foyers is one, occupy hanging valleys relatively to Loch Ness, towards which they descend by a succession of rapids and waterfalls.

Breac, nam.—Irregularly shaped rock-basin in Lewisian Gneiss, with numerous islands and uneven floor.

Breac Dearga, nam.—Rock-basin in hollow traversing the Middle Old Red Sandstone rocks on the northern face of Meallfourvounie.

Breaclaich.—Rock-basin.

Broom.—Drift-dammed.

Brora.—Valley rock-basin in granulitic schists where the valley becomes constricted between the Middle Old Red Conglomerate hills, Ben Smeorail (1592 feet) on the north and Ben Horn (1708 feet) on the south. Four separate basins occur on the floor of the lake.

Brough.—Resting on Old Red Sandstone and ponded by drift.

Brouster.—Chain of lakes in valley carved out of altered Old Red Sandstone strata.

Brow.—In drift, separated from Loch Spiggie by delta of Burn of Hill.

Bruadale.—Upper part of Loch Urrahag.

Buaille, a'.—Rock-basin in Lewisian Gneiss.

Buidhe (Fleet basin, Sutherland).—Rock-basin in crystalline schists, water-level now raised by artificial embankment.

Buidhe (Tay basin).—Drift-dammed.

Builg.—Ponded by moraines at both ends, and lying in a glaciated hollow on the pass between the Builg-Avon and Glen Gairn streams.

Bunacharan.—Vol. II. Part I. p. 353.

Burga Water.—Rock-basin in altered Old Red Sandstone.

Burntisland.—Artificial reservoir on Lower Carboniferous volcanic platform.

Burraland.—Small rock-basin in granite and schists.

Butterstone.—Partly drift-dammed, in hollow along line of shatter-belt of Highland Border fault.

Calavie.—Vol. II. Part I. p. 353.

Calder.—Rock-basin in Caithness flagstones. The south-eastern straight shore-line is determined by a line of fault which can be traced northwards to the Forss Water.

Callater.—Valley rock-basin in Highland schists (phyllites, black schist, and quartzite).

Càm.—Vol. II. Part I. p. 189.

Caol na Doire.—Rock-basin in Moine schists.

Caravat.—Rock-basin in Lewisian Gneiss; tide sometimes enters the loch.

Carlingwark.—Hollow in drift resting on greywackes and shales.

Castle (Annan basin).—Kettle-hole in fluvio-glacial deposits; one of the Lochmaben lochs.

Castle (Bladenoch basin).—Rock-basin in Silurian greywackes.

Castle Semple.—Drift-dammed, probably a large kettle-hole formed by a lobe of ice isolated from the retreating northern glacier, round which fluvio-glacial deposits were laid down. The loch is now largely silted up by detritus introduced by tributary streams.

Ceithir Eileana, na.—Rock-basin in Lewisian Gneiss.

Ceò-Glas.—Small rock-basin draining into Loch Dùn na Seilcheig on plateau above Loch Ness (see Loch Bran).

Chaluim.—Shallow drift-dammed loch with moraines forming islands and promontories.

Chaoruinn, a'.—Rock-basin in crystalline schists and epidiorite.

Chlachain, a' (Lewis).—Rock-basin in Lewisian Gneiss, through which the river Creed flows.

Chlachain, a' (Nairn basin).—Rock-basin, partly drift-dammed.

Chladaich, a'.—Rock-basin in Lewisian Gneiss.

Chlàir, a' (Helmsdale basin).—Part of same drift-dammed hollow as Baddanloch.

Choire, a'—Resting partly on schists and partly on drift on platform above Loch Ness. It flows into Loch Ruthven.

Chon (Forth basin).—Vol. II. Part I. p. 50.

Chroisg, a'.—Vol. II. Part I. p. 289.

Chuilinn, a' (Conon basin).—Vol. II. Part I. p. 289.

Clair (Ewe basin).—Vol II. Part I. p. 240.

Claise Feàrna, na.—Rock-basin in Lewisian Gneiss.

Clickhimin.—Drift-dammed in hollow of Old Red Sandstone.

Cliff.—Ponded by gravel at the margin of the present beach.

Clings Water.—Rock-basin in altered Old Red Sandstone strata, partly drift-dammed.

Clousta.—Resting partly on Old Red Sandstone and partly on drift.

Clubbi Shuns.—Small rock-basin in granite of Roeness Hill, Shetland.

Clunie (Ness basin).—Valley rock-basin in schists and granite; simple U-shaped basin with irregular sides strewn with moraines.

Clunie (Tay basin).—Small shallow lake ponded by drift.

Coinnich, na.—Ponded by drift.

Coir' an Fheàrna.—Rock-basin along strike of crystalline schists in valley open at both ends, which drained part of the ice from Central Sutherland (see Loch a' Bhealaich).

Coire nam Meann.—Rock-basin in Moine schists.

Collaster.—Partly on rock and partly in drift.

Cornish.—Ponded by drift in hollow near the edge of the Loch Doon granite mass.

Coulin (Ewe basin).—Vol. II. Part I. p. 240.

Craggie (Oykell).—Rock-basin in Moine schists.

Craige, na.—Small drift-dammed loch lying on crystalline schists.

Crann.—Vol. II. Part I. p. 289.

Craobhaig, na.—Rock-basin in Lewisian Gneiss.

Creagach.—Vol. II. Part I. p. 329.

Creige Léithe, na.—Rock-basin in Lewisian Gneiss separated by a bar of stones from Loch nan Garbh Chlachan.

Crò Criosdaig.—Rock-basin in Lewisian Gneiss.

Cròcach.—Vol. II. Part I. p. 188.

Crogavat.—Rock-basin in Lewisian Gneiss.

Crombie Den.—Artificial reservoir in hollow cut out of boulder clay and Lower Old Red strata by stream.

Crunachan.—Remnant of a loch in drift nearly silted up.

Cuaich, na.—Rock-basin in Moine schists.

Cuil Airidh a' Flod.—Rock-basin in Lewisian Gneiss.

Cùil na Síthe.—Ponded by drift.

Cuinne, nan.—Hollow in drift resting on Moine schists.

Cults.—Kettle-hole in fluvio-glacial deposits of 100-ft. raised beach.

Daimh, an (Shin basin).—Vol. II. Part I. p. 307.

Daimh (Tay basin).—Rock-basin in crystalline schists.

Dallas.—Kettle-hole in fluvio-glacial deposits.

Damh (Torridon basin).—Rock-basin in valley open at both ends. The lower end of the lake lies in Lewisian Gneiss, which here forms a pre-Torridonian hill projecting through the basal members of the Torridon Sandstone, and the remainder rests on that formation.

The upper part of the loch, which is outside the valley, follows the line of shatter-belt of the Fasagh fault. The valley in which the greater part of Loch Damh is situated formed an outlet for the large mass of ice that flowed into Loch Torridon. It is evident that the Lewisian Gneiss has resisted erosion more successfully than the Torridon arkoses.

Davan.—In glacial deposits.

Deaspoirt, nan.—Irregular rock-basin in Lewisian Gneiss; one of a chain of similar rock-basins.

Dee.—Rock-basin in granite, partly ponded by drift.

Déighe fo Dheas, na.—Rock-basin in Lewisian Gneiss.

Deoravat.—Rock-basin in Lewisian Gneiss.

Derclach.—Small rock-basin in greywackes, whose waters flow into Loch Finlas.

Derculich.—Rock-basin in phyllites and limestone.

Dhomhnuill Bhig.—Irregular rock-basin in Lewisian Gneiss.

Dhù (Portsonachan Hill).—Resting partly on drift and partly on metamorphic rocks.

Dhùgaill (Torridon basin).—Rock-basin in Torridon Sandstone along line of shatter-belt.

Dhùghaill (Carron basin).—Ponded by moraines and fluvio-glacial material. The deepest part is probably a rock-basin lying in crystalline schists and Cambrian strata along the line of the Moine thrust-plane and the Glenmore fault. The lake evidently extended along the valley to Craig, but has been silted up by the alluvium of the Carron and its tributaries.

Dibadale.—Corrie rock-basin in Lewisian Gneiss.

Dilate.—Small rock-basin in crystalline schists, draining into Loch Sheil.

Dithreibh, an.—Vol. II. Part I. p. 331.

Dochard.—Rock-basin in crystalline schists.

Dochart.—Vol. II. Part I. p. 138.

Doine.—Vol. II. Part I. p. 45.

Doire Daraich, na.—Rock-basin in Lewisian Gneiss.

Doire nam Mart.—Rock-basin in crystalline schists, probably along shatter-belt (see *ante*, Loch Arienas).

Doon.—Typical rock-basin in Lower Silurian strata and granite. It has two distinct basins. The upper and deeper one lies in the granite, its barrier being composed of the belt of hornfels that crosses the loch near the Wee Hill of Craigmulloch; the lower one is situated in Silurian strata, whose outlet is a tunnel driven through a well-glaciated *roche moutonnée* of greywacke. The Gull Islands and the shores of the Ford of Moak consist of moraines, while the islands in Garpel Bay are *roches moutonnées*.

Dornal.—Ponded by boulder clay and moraines, resting on Silurian greywackes.

DROIGHINN, AN.—Rock-basin in volcanic rocks of Lorne plateau.

DROMA.—Ponded by moraines and alluvium, partly artificial. It is situated on the main watershed of the North-West Highlands. In this case the ice-shed must have lain far to the east of the present watershed, as shown by the distribution of boulders of the well-known augen gneiss of Inchbae, which can be traced across to Loch Broom. Such watersheds have almost invariably had the gradients on each side lessened, while many have been hollowed into rock-basins.

DRUIM SUARDALAIN.—One of a chain of rock-basins in Lewisian Gneiss, along the course of the stream that drains Glen Canisp.

DRUIMNEAN, NAN.—Rock-basin along strike of phyllites, partly drift-dammed.

DRUMLAMFORD.—Hollow in boulder clay and moraine matter resting on Silurian greywackes and shales.

DRUNKIE.—Vol. II. Part I. p. 49.

DUARTMORE.—Small rock-basin in Lewisian Gneiss on the Duartmore river.

DUBH (Etive basin).—Small shallow pool among moraines on the Lower Old Red volcanic plateau of Lorne.

DUBH (Forth basin).—Lochan in drift much silted up.

DUBH (Gairloch basin).—Rock-basin in Lewisian Gneiss, draining into Loch Bad an Sgalaig.

DUBH (Gruinard basin).—Rock-basin in Lewisian Gneiss, part of the Fionn Loch rock-basin, from which it is separated by a bar of moraine matter with only a shallow strait.

DUBH (Ness basin).—Ponded by drift.

DUBH (nan Uamh basin).—Rock-basin in crystalline schist on watershed between the heads of Lochs Eilort and nan Uamh.

DUBH-MÒR.—Rock-basin in epidiorite and schists of Loch Awe group at base of escarpment of the Lorne volcanic plateau.

DUDDINGSTON.—Remnant of a much larger lake, now mostly silted up, originally ponded by blown sand of the 100-ft. raised beach. From the position of Duddingston Loch with regard to the crags of Arthur's Seat, it is probable that part of it is a true rock-basin.

DUIN, AN (Spey basin).—Rock-basin in Moine schist on the pass between the Tromie, flowing into the Spey, and the Edendon Water, flowing into the Garry and thence to the Tay.

DÙIN, AN (North Uist).—Tidal loch; probably a rock-basin in Lewisian Gneiss.

DÙNA, AN.—Rock-basin in Lewisian Gneiss.

DUNGEON.—Rock-basin partly ponded by drift in greywackes and shales of Silurian age. The barrier at the outlet is a moraine, but the deeper part of the loch must be a rock-basin.

DÙN NA SEILCHEIG.—Rock-basin resting partly on crystalline schists and partly on Old Red Sandstone, with some moraines lying on the rocky barrier at the outlet.

EAGLAIS, NA H-.—Kettle-hole in fluvio-glacial deposits of 100-ft. raised beach.

Ealaidh, na h-.—Shallow loch, mostly in alluvium, and separated from Loch More by a moraine and from Loch Stack by alluvium. It was formerly continuous with Loch Stack, but has been disconnected by a cone of alluvium.

Earba, na h-.—Rock-basin in crystalline schists, now forming separate lakes owing to alluvial cones or deltas. The basin is U-shaped, and lies in a valley between high mountains.

Earn.—Vol. II. Part I. p. 138.

Eck.—Valley rock-basin across the strike of the crystalline schists in the valley of the river Cur; in reality a watershed rock-basin. The head of the lake is much silted up.

Ederline.—Typical kettle-hole surrounded by high terraces of fluvio-glacial gravels and lake deposits. It probably lies in the continuation of the Loch Awe rock-basin, but has evidently been formed during the retreat of the great Loch Awe glacier, when a detached lobe of ice was left on the present site of the lake, round which the fluvio-glacial gravels were laid down (see Loch Awe).

Edgelaw.—Artificial reservoir in valley cut out of drift and Lower Carboniferous strata.

Eela Water.—Resting partly on drift and partly on rock composed of schists and granite.

Eigheach.—Expansion of the river Gaur; rock-basin in Rannoch Moor granite massif along line of the Loch Laidon shatter-belt.

Éilde Mòr.—Rock-basin in crystalline schists and Glencoe quartzite, along line of shatter-belt that determines the direction of Loch Leven on the one side and Loch Treig on the other.

Eileach Mhic 'ille Riabhaich.—Small rock-basin in Lewisian Gneiss; an expansion of the Little Gruinard river, which drains the Fionn Loch.

Eilein, an (Gairloch basin).—Rock-basin in Lewisian Gneiss and Torridon Sandstone.

Eilein, an (Spey basin).—Kettle-hole in fluvio-glacial deposits.

Eilt.—Rock-basin in granulitic schists, containing three minor basins separated by rocky barriers.

Eion Mhic Alastair.—Kettle-hole in fluvio-glacial deposits of 100-ft. raised beach.

Eldrig.—Ponded by drift.

Ericht.—Rock-basin in granulitic schists and granite along the line of the Loch Laidon shatter-belt. It occupies a valley open at both ends, which acted as one of the outlets for the ice from the Rannoch Moor cauldron. The basin is deepest where the hollow is most constricted, and ceases where it opens into the wider valley of Glen Truim. The barrier which separates the end of the loch from Glen Truim is moraine-covered.

Essan.—Ponded by drift, and resting on limestone and schist, and situated practically on the watershed.

Eun, nan (N. Uist).—Rock-basin in Lewisian Gneiss.

EUN, NAN (Tay basin).—Small tarn on high plateau. A rock-basin in dark schist and limestone, which may be partly due to solution.

EYE.—Vol. II. Part I. p. 290.

FAD.—Partly rock-basin and partly drift-dammed along the line of shatter-belt of Toward Point fault, bringing Upper Old Red Sandstone into conjunction with Highland schistose rocks.

FADA (Ewe basin).—Rock-basin in Lewisian Gneiss, Torridon Sandstone, and Cambrian strata. The upper end is crossed by the shatter-belt of the Fasagh fault, which also determines its outlet.

FADA (Gruinard basin).—Rock-basin in Lewisian Gneiss.

FADA (N. Uist).—Irregular rock-basin in Lewisian Gneiss.

FADAGOA.—Irregular rock-basin in Lewisian Gneiss, along the strike of the rocks.

FANNICH.—Vol. II. Part I. p. 288.

FAOILEAG, NAM.—Irregular rock-basin in Lewisian Gneiss.

FENDER.—Partly in crystalline schists and partly drift-dammed.

FIART.—Rock-basin in metamorphic limestone associated with black schist along crest of anticline, partly due to ice erosion and partly to solution. The black schist underlies the limestone and forms the retentive layer, the level of the lake determining the saturation of the limestone in the synclines (see Baile a' Ghobhainn, *ante*, p. 489).

FINLAS.—Partly a rock-basin in Lower Silurian greywackes, and partly ponded by drift.

FIODHAIG.—Rock-basin in granulitic schists.

FIONN (Gruinard basin).—Rock-basin in Lewisian Gneiss, drained by the Little Gruinard river, which leaves the loch by a series of rapids and waterfalls. It is one of the few Scottish lakes which fork downwards towards its outlet—a fact of great importance in relation to the theory of ice-erosion, as shown by Penck.

FIONN (Kirkaig basin).—Vol. II. Part I. p. 188.

FITHIE.—Resting on Old Red Sandstone, and ponded by drift.

FITTY.—Partly artificial, and lying in drift.

FLEET.—Resting partly on rock (granite) and partly in drift.

FLUGARTH.—Partly drift-dammed and partly a rock-basin in schist.

FORFAR.—Kettle-hole ponded by drift.

FREUCHIE.—Partly a rock-basin in schists and partly ponded by drift.

FRISA.—Valley rock-basin in Tertiary volcanic plateau, Mull. The direction of the valley has evidently been determined by the lines of fissure followed by the great series of Tertiary basic and acid dykes. The valley is open at both ends, and thus received a larger volume of ice than would have fallen to its share had it been closed at the head.

FYNTALLOCH.—Hollow in boulder clay resting on Silurian greywackes. It drains into Loch Ochiltree.

GABHAR, NAN.—Drift-dammed shallow loch at foot of Glen Gour. It must have been filled with ice when the raised beaches at Corran were being formed.

Gainmheich.—Valley rock-basins in Lewisian Gneiss and Torridon Sandstone.

Gamhna.—Kettle-hole in fluvio-glacial materials.

Garbh-Abhuinn, na.—Rock-basin in Lewisian Gneiss.

Garbh-Abhuinn Ard, na.—Rock-basin in Lewisian Gneiss.

Garbhaig.—Vol. II. Part I. p. 239.

Garbh-Clachan, nan.—Rock-basin in Lewisian Gneiss.

Garry (Ness basin).—Simple rock-basin down as far as Garbh Eilean, below which there is a shallow expansion with a waterfall near the outlet.

Garry (Tay basin).—Rock-basin in granulitic schists along shatter-belt. The steep-sided valley in which it lies has been pirated from the Spey system by a tributary of the Tay. The great suite of moraines emanating from this valley, traceable far down the Garry, shows what a powerful glacier must have occupied the site of this loch during the later glaciation.

Gartmorn.—Artificial reservoir on boulder clay resting upon Upper Carboniferous strata.

Garve.—Vol. II. Part I. p. 289.

Gead, an.—Vol. II. Part I. p. 353.

Geal.—Typical delta loch cut off from Loch Lomond and enclosed in the advancing delta of the Falloch. Loch Buidhe at the head of Loch Lubnaig has a similar origin.

Gealaich, na.—Moraine-dammed on quartzite and epidiorite.

Geireann, nan.—Tidal loch; probably a rock-basin along the strike of the Lewisian Gneiss.

Geireann, nan (Mill).—Rock-basin in Lewisian Gneiss.

Gelly—Partly artificial, in drift resting on Lower Carboniferous strata.

Ghiuragarstidh.—Vol. II. Part I. p. 240.

Ghlinne-Dorcha, a'.—Rock-basin in Lewisian Gneiss.

Ghobhainn, a'.—Rock-basin in Lewisian Gneiss.

Ghriama, a'.—Rock-basin in Moine schists.

Ghuilbinn.—Valley rock-basin in Strath Ossian.

Giorra.—Rock-basin in crystalline schists.

Girlsta.—Rock-basin in crystalline schists and metamorphic limestones; may be partly due to solution.

Gladhouse.—Artificial reservoir in wide valley carved out of Upper Old Red Sandstone and overlaid by boulder clay.

Glass.—Vol. II. part I. p. 290.

Gleann a' Bhearraidh.—Rock-basin along fault throwing down the Lower Old Red volcanic rocks of the Lorne volcanic plateau against the underlying sediments and crystalline schists.

Gorm Loch Mòr.—Vol. II. Part I. p. 307.

Gown.—Ponded by moraines and fluvio-glacial gravels of the Achnasheen terraces.

Grass Water.—Lying in boulder clay.

GRENNOCH.—Rock-basin in the granite massif of Cairnsmore of Fleet.

GRUNAVAT.—Rock-basin in Lewisian Gneiss.

GRYFE.—Artificial reservoir, partly in boulder clay and partly in Lower Carboniferous volcanic rocks of the Renfrewshire plateau.

HARELAW.—Artificial reservoir on Malleny Burn. It occupies a hollow cut out of boulder clay overlying Lower Carboniferous rocks.

HARPERLEAS.—Artificial reservoir, partly in boulder clay and partly in Lower Carboniferous strata.

HARPERRIG.—Artificial reservoir in wide open valley, partly in Lower Carboniferous rocks and partly in boulder clay covered in places by peat and alluvium.

HARRAY.—Rock-basin in Middle Old Red flagstones, separated from the Loch of Stenness by a shallow rock-floored channel over which salt water from Loch Stenness occasionally flows.

HARROW.—Partly ponded by drift and partly a rock-basin in greywackes and shales.

HEILEN.—Impounded on north side by blown sand of Dunnet Links. It lies partly in boulder clay and partly in Caithness flagstones.

HEMPRIGGS.—Shallow loch in boulder clay lying on Caithness flagstones.

HEOURAVAY.—Irregular rock-basin in Lewisian Gneiss.

HERMIDALE.—Irregular rock-basin in Lewisian Gneiss.

HIGHTAE MILL.—Kettle-hole in fluvio-glacial deposits. One of the Lochmaben lochs.

HOGLINNS.—Small rock-basin in Upper Old Red Sandstone of Hoy.

HOLL.—Artificial reservoir, partly in boulder clay resting on Lower Carboniferous strata and intrusive dolerite.

HOPE.—Vol. II. Part I. p. 328.

HOSTA.—Rock-basin in Lewisian Gneiss.

HOSTIGATES.—Rock-basin in Old Red Sandstone.

HOWIE.—Partly in Silurian greywackes and partly drift-dammed.

HUNA.—Partly in Lewisian Gneiss and partly ponded by drift.

HUNDER.—Rock-basin in Lewisian Gneiss.

HUNDLAND.—Partly in Old Red flagstones and partly in boulder clay.

IASGAICH, AN.—Hollow in Lewisian Gneiss.

IC COLLA.—Rock-basin in Lewisian Gneiss.

INBHIR.—Minor rock-basin in granite and schist studded with moraines. One of the outlets from the Rannoch Moor ice-cauldron, now covered by the Leven reservoir (see Loch a' Bhaillidh).

INSH.—Remnant of a much larger lake in the Spey valley ponded by moraines and fluvio-glacial deposits from the Glen Feshie glacier at a time when the Spey glacier failed to reach and coalesce with it. The lake is now almost silted up by the Spey.

ISBISTER.—Ponded by drift.

IUBHAIR.—Vol. II. Part I. p. 138.

KATRINE —Vol. II. Part I. p. 48.

KEMP.—Rock-basin on the platform above Loch Ness (see Loch Bran).

Ken.—Succession of shallow rock-basins along the course of the Kirkcudbrightshire Dee and its main tributary the Ken. They lie across the strike of the Silurian greywackes and shales.

Kennard.—Lies partly in drift and partly on rock.

Kernsary.—Vol. II. Part I. p. 239.

Kilbirnie.—Ponded by drift and now much silted up. It is situated near the watershed in a valley open at both ends which formed an outlet for the Highland ice escaping from the Clyde valley.

Kilcheran.—Rock-basin in limestone resting on schist, resembling Loch Fiart and Loch Baile a' Ghobhain already described.

Kilchoan.—Small rock-basins in dark slates and epidiorites—the most southerly one is along a line of fault which brings down the Lorne volcanic rocks against the Craignish phyllites and limestones.

Kilconquhar.—Kettle-hole in 100-ft. raised beach deposits.

Killin.—Valley rock-basin in schists.

Kindar.—Small basin partly in Criffel granite and partly ponded by drift.

Kinellan.—Partly in Middle Old Red Sandstone strata and partly in drift.

Kinghorn.—Reservoir. Hollow in drift.

Kinord.—Ponded by fluvio-glacial deposits.

Kirbister.—Drift-dammed on Middle Old Red flagstones.

Kirk.—Kettle hole in fluvio-glacial gravels; one of the Lochmaben lochs.

Kirk Dam.—Part of Loch Fad (Bute), separated from it by an artificial dam (see Loch Fad).

Kirriereoch.—Ponded by drift resting on Silurian greywackes and shales.

Knockie.—Partly a rock-basin and partly drift-dammed.

Lagain, an (Shin basin).—Drift-dammed.

Laggan (Lochy basin).—Rock-basin, partly ponded by moraines and fluvio-glacial deposits. The loch is of special interest owing to its situation, which is practically on the watershed between the Spean and a tributary of the Spey. In pre-glacial time the Spean pirated a large part of the Spey system, and thus a through valley was established which became an outlet for a large volume of ice during the glacial period, whereby the col was subjected to intense erosion. Loch Laggan is the remnant of the temporary ice-dammed lake whose limits are now defined by the 800-ft. parallel road, the level of which was determined by the col between the Spean and the Spey. The river Pattack has silted up the upper part of Loch Laggan.

Laghair, an.—Valley rock-basin in granulitic schists continuous with that of Loch Beinn a' Mheadhoin, from which it is separated only by delta deposits (see Beinn a' Mheadhoin).

Laide.—Ponded by drift.

Laidon.—Shallow rock-basin in Rannoch Moor granite massif along line of shatter-belt. The Dubh Lochan is a very shallow expansion along a tributary valley, this part of the loch being strewn with moraines.

LAIRIGE, NA.—Rock-basin on the pass between Loch Tay and Glen Lyon. It is important chiefly on account of its position, which is expressed by its Gaelic name, signifying the Loch of the Pass.

LANGAVAT (Benbecula).—Rock-basin along strike of Lewisian Gneiss. Rocky islands also elongated along strike.

LANGAVAT (Lewis).—Long valley rock-basin across the strike of the Lewisian Gneiss. It contains several minor basins along the strike of weak rocks, eight or more of which are below the 25-ft. contour line, four below the 50-ft. line, and three below the 75-ft. line. The loch is manifestly due to ice erosion.

LANN, NAN.—Small rock-basin in schists on same stream as Loch Knockie. It is one of a chain of lakes already referred to, situated on a plateau overlooking Loch Ness (see Loch Bran).

LAOGHAL.—Vol. II. Part I. p. 329.

LEITIR EASAICH.—Vol. II. Part I. p. 188.

LEITREACH, NA.—Rock-basin in Moine schist along line of shatter-belt of Strath Conon fault, which here determines the direction of the valley of the Elchaig. Loch Muirichinn, at the head of the valley, is a lake of similar origin, placed at or near the watershed between the river Elchaig and the river Ling, the pass having formed one of the outlets from the Monar ice-cauldron.

LEODSAY.—Tidal loch in Lewisian Gneiss.

LEÒID, AN.—Rock-basin in Lorne volcanic plateau.

LEUM A' CHLAMHAIN.—Rock-basin in granulitic schists situated where the ice became constricted in passing between the outliers of Old Red Conglomerate forming the two Ghriam hills in the east of Sutherland.

LEVEN.—Large kettle-hole in fluvio-glacial and lake deposits. It must have been occupied by a lobe of the Forth glacier while fluvio-glacial material from the Tay glacier was poured into the Kinross valley through the passes of the Ochils. Originally of larger dimensions, it has been drained partly naturally by the river Leven and partly artificially. The shores of the loch are composed mostly of its own alluvia, or of deltas laid down by tributary streams.

LIATH.—Partly a rock-basin and partly ponded by drift.

LINDORES.—Kettle-hole in fluvio-glacial deposits formed during the retreat of a lobe from the Tay glacier pushed into the Dunbog valley, which poured its melt-waters over the passes into the great temporary ice-dammed lake that filled the Howe of Fife, a remnant of which is now represented by Ramornie Loch. Other kettle-holes occur in these deposits (see Black Loch).

LINLITHGOW.—Ponded by drift. Probably a kettle-hole in fluvio-glacial deposits left by a lobe of the Forth glacier during its retreat near the end of the period of maximum glaciation.

LINTRATHEN.—Rock-basin in Lower Old Red Sandstone and Conglomerate, the dam consisting of the Lintrathen porphyry. The loch is much silted up by the Melga Water, which flows through it.

Littlester.—In drift on gneiss.

Loch.—Rock-basin in schists and limestones between the quartzites of Ben-y-Ghloe.

Lochaber.—Lies partly on granite, partly on Silurian greywackes, and partly on glacial deposits.

Lochenbreck.—In drift resting on Silurian greywackes and shales.

Lochindorb.—Hollow in fluvio-glacial deposits.

Lochinvar.—Lying partly on Silurian greywackes and shales and partly in drift.

Lochnaw.—Small lochan, partly in greywackes and partly drift-dammed.

Lochrutton.—Partly in Silurian greywackes and shales and partly in drift.

Lochy.—Rock-basin along shatter-belt of Great Glen fault.

Lomond.—This lake may be regarded as a typical valley rock-basin lying across the strike of the strata in a valley in great part excavated by one of the original consequent streams of Scotland draining towards the south-east.

The loch may be divided into two sections:—(1) an upper or Highland section, extending from its head to Luss and the islands of Inchlonaig and Inchtavannoch lying in metamorphic rocks; (2) a lower or Lowland section, extending from the above-mentioned islands to the foot of the loch, partly in Highland schists but chiefly in strata of Old Red Sandstone age.

The upper section is situated in a narrow valley whose direction is in great part determined by a system of joints and faults with a nearly north-and-south trend. Before the glacial period the consequent river had excavated a channel across the belt of schistose grit which now forms the barrier between the upper and lower sections. Throughout the Ice Age the direction of the ice-flow in the present region was southerly—that is, approximately, down the loch. The basin lies in comparatively soft mica-schists where the valley is narrowest and steepest. It is bounded by the 400-ft. contour line, and contains two minor basins below the 500-ft. line, within one of which occurs the deepest sounding (623 feet). Near Rowardennan the outcrop of the Ben Ledi grits crosses the lake, and the upper or deep basin suddenly gives place to a shallow plateau with two islands, the deepest sounding here being only 49 feet. It is doubtless true that the Douglas Burn has laid down a delta extending into the lake from the west shore, and that a spit has been formed at Rowardennan on the eastern bank; but the shallow plateau is not due to these accumulations. It may rather be said that its existence led to the deposition of these materials.

Below this barrier a second but shallower basin occurs in the upper section. Here the valley widens, and the hills, though high, recede to some extent. The lake, however, does not appreciably widen near the upper end of the basin, probably because the rocks consist of alternations of strong and weaker schistose grits. This basin is continued in a north-and-south direction till it reaches an outcrop of strong grit forming Ross Point which juts far out into the loch from the eastern shore. The grit is obliquely truncated by a fault that brings the mica-schists against the Luss slates on the west side of the lake. Hence the rock-basin is continued round the Ross Point in the softer strata. Beyond this promontory the loch widens in the line of outcrop of the Luss slates. Below Luss, the slates are succeeded by massive pebbly grits, forming a shallow plateau on which are situated the islands of Inchtavannoch and Inchlonaig. Below the 100-ft. contour line only a narrow channel between Inchlonaig and Strathcashell is to be found crossing this rocky barrier, the others being much shallower.

In the lower section of the loch the valley widens, and opposite the Endrick and the Fruin it merges into the Lowland plain. This change in the configuration of the surface may be attributed to the Highlands schists having been covered by strata of Old Red Sandstone age. The sudden widening of the loch below the islands of Inchtavannoch and Inchlonaig is evidently due to the removal in pre-glacial time of the Upper Old Red sandstones and conglomerates from the old plain of denudation of Highland schists upon which they were originally laid down. Between a line drawn across the lake from Rossdhu House to Arrochymore Point and the Highland Border fault, which traverses the islands of Inchcailloch and Inchmurrin, the floor of the loch is formed of Upper Old Red Sandstone strata, which there dip at comparatively low angles to the south-east. The shatter-belt of the Highland fault is here much indurated with carbonates, and is flanked on the south side by nearly vertical beds of Lower Old Red conglomerate. These together form a prominent barrier and a chain of islands. The conglomerates are succeeded by the softer sandstones dipping less steeply to the south-east. As might be expected from the widening of the valley and its coalescence with the plain, this part of the lake is shallow. The lowest portion may not be a rock-basin, for the valley of the Leven is floored with raised beach deposits and alluvium.

There is evidence to prove that in late glacial time the lower part of the loch was an arm of the sea, for deposits of clay with arctic shells are found at Rossdhu and on Inchlonaig, which are supposed to belong to the 100-ft. raised beach. This shelly clay has not been met with higher up, from which it may be inferred that the upper part of the lake was occupied by the retreating glacier during the time of its deposition. If this correlation be correct, there must have been a recrudescence of glacial conditions, for the Inchlonaig deposits are overlain by a red shelly boulder clay which can be traced far beyond the present foot of the lake. The remains of the lower raised beaches are found at intervals nearly up to the head of the loch, so that during their formation the ice had retreated from the whole valley.

Since that time, Loch Lomond has been silted up to some extent by the Fruin and the Endrick near its foot, and by the Falloch at its head, and the delta of the Falloch has isolated a part of the lake, thus forming the Geal or White Loch, a typical delta lake.

Losgainn Mòr, an.—Rock-basin in schists and epidiorite, with morainic material along its banks. Its lower end has been silted up by streams entering it from the south.

Losganan, nan.—A mere pool in drift.

Lowes (Tay basin).—Ponded by drift resting on schistose grits.

Lowes (Tweed basin).—Upper end of St Mary's Loch, and separated from it by deltas (see St Mary's Loch).

Loyne.—A chain of shallow rock-basins in Glen Loyne, partly silted up.

Lubnaig.—Vol. II. Part I. p. 45.

Luichart.—Vol. II. Part I. p. 288.

Lundie (Glen Garry).—Irregularly shaped loch, partly a rock-basin and partly ponded by moraines.

Lungard.—Typical valley rock-basin in crystalline schists near the head of Glen Cannich.

Lùnn dà Bhrà.—Shallow lake with moraines practically on the watershed.

Lure.—Ponded by drift resting on Silurian greywackes and shales.

Lurgain.—Vol II. Part I. p. 190.

Lyon.—Valley rock-basin in crystalline schists along line of Tyndrum fault.

Maberry.—In boulder clay and moraines overlying Silurian greywackes and shales.

Magillie.—Kettle-hole in fluvio-glacial deposits.

Màma.—Rock-basin in schists, separated from Loch na Creige Duibhe by delta of Allt Dearg.

Maol a' Choire.—Vol. II. Part I. p. 191.

Maree.—Composite rock-basin, partly along the Glen Docherty shatter belt, and partly in Lewisian Gneiss and Torridon Sandstone outside of this line of disturbance. The horizontal displacement of the geological structure lines in the neighbourhood of Kinlochewe, and the shattering of the rocks are prominent features of this disruption. It also has a down-throw of 1000 feet to the north-east. It enters the lake at its head, and runs near the northern shore to a point opposite Eilean Subhainn, where it leaves the loch and traverses the precipitous slope behind Ardlair. Beyond that mansion-house it once more enters the lake, passes down the River Ewe to within a mile of Poolewe, and extends north-west to Camas Mòr east of the Rudh' Re.

The soundings show that the lake contains three basins. The upper one, extending from the head of the loch to a point opposite

Eilean Subhainn, is U-shaped, the deepest portion occurring where the valley is most constricted, between Ben Slioch (3217 feet) on the north and Meall a' Ghubhais (2882 feet) on the south. Between Regoilachy and Coppachy the effect of a branch fault in weakening the strata is shown by the widening of the basin and the loop of the 250-ft. contour line in that portion of the lake.

The Ardlair basin, beyond the islands, is a composite one. The north-west portion, north of Rudh' Aird an Anail, is situated in the line of the great shatter-belt, and is U-shaped; but the wider and deeper part of the same basin, lying between that promontory and Eilean Ruairidh Mòr, is evidently due to the removal of comparatively weak strata, consisting of the lowest division of the Torridon Sandstone, from the old floor of Lewisian Gneiss on which it was deposited.

The Slattadale basin rests in Torridonian strata, belonging partly to the Applecross grits and partly to the weaker beds of the Diabaig group. A striking feature of this part of the lake is the number and size of the islands, which are composed mostly of massive Torridon sandstones and grits. One of these, Eilean Subhainn, contains a rock-basin 64 feet in depth.

The river Ewe, which drains the loch, has cut a channel through the deposits of the 50-ft. raised beach, and runs for about half a mile over Torridonian strata before entering the sea.

Loch Maree evidently extended farther up the valley, but it has been silted up by the streams that converge near Kinlochewe. This part of the lake was probably comparatively shallow, as Eilean na Craoibhe, near the head of the existing loch, is a moraine more or less levelled by the action of the waves.

Martnaham.—Kettle-hole in fluvio-glacial deposits.

Meide, na.—Rock-basin in Moine schists. It drains into Loch Naver, and is situated on the pass leading to the Kyle of Tongue, along one of the outlets of the Mid-Sutherland ice-cauldron between Ben Loyal and Ben Hope.

Meiklie.—Remnant of partly silted up rock-basin in crystalline schists in Glen Urquhart.

Menteith.—Vol. II. Part I. p. 52.

Merkland.—Rock-basin in Moine schists, partly ponded by drift and partly silted up.

Mhic 'Ille Riabhaich.—Ponded by moraines.

Mhiotailt.—Vol. II. Part I. p. 189.

Mhor (Ness basin).—Artificial reservoir for Foyers Aluminium Works. It covers the site of Lochs Garth and Farraline, small rock-basins on the plateau above Loch Ness (see Loch Bran).

Mhuilinn, a'.—Vol. II. Part I. p. 353.

Migdale.—Partly in crystalline schists and partly drift-dammed.

Mill.—Kettle-hole in fluvio-glacial gravels. One of the Lochmaben lochs.

Milton.—Ponded by drift resting on Silurian greywackes and shales.

Mochrum.—Rock-basin in Silurian greywackes.

Moine, na.—Small drift-dammed loch on one of the main branches of the Helmsdale river.

Moine Buige, na.—Rock-basin in Lewisian Gneiss.

Monar.— Vol. II. Part I. p. 352.

Monikie.—Artificial reservoirs in boulder clay resting on Lower Old Red Sandstone.

Moor Dam.—Artificial reservoir in boulder clay resting on Upper Carboniferous strata.

Moracha, na.—Rock-basin in Lewisian Gneiss.

Morar.—Typical rock-basin in granulitic schists. Although the head of the loch lies only a few miles from the watershed, there are several low passes in a high mountainous region connecting it with the valleys draining into the Great Glen (1) by Glen Pean (under 500 feet) into Loch Arkaig valley, (2) by Glen Dessary (under 1000 feet) into Glen Kingie towards Glen Garry, (3) by Loch Beoraid over the col (under 1000 feet) into Loch Eil, besides other higher gaps. During part of the glacial period the ice must have streamed over these passes and concentrated upon Loch Morar. At the lower end of the lake, where the valley widens there is a shallow platform with *roches moutonnées*. The ridge between Loch Morar and Loch Nevis is studded with small lakes, evidently due to ice-erosion.

More (Laxford basin).—Ponded by moraine in a valley carved out of Lewisian Gneiss, Cambrian strata, and the overlying Moine schists. Although the barrier between Loch More and Loch Stack is a moraine, there is every reason to believe that the rock-basin of Loch Stack is continuous with that of Loch More.

More (Thurso basin).—Remnant of a larger loch through which the Thurso River flows. It lies in a hollow of the drift; but it seems highly probable that the drift conceals a rock-basin, as the river at Dirlot is excavating a rock gorge through the local basement members of the Caithness flagstones into the underlying schists.

More Barvas.—Ponded by blown sand in a hollow of the Lewisian Gneiss.

Morie.—Vol. II. Part I. p. 290.

Morlich.—Probably a kettle-hole in morainic and fluvio-glacial material. The hill-slopes above are terraced with moraines, each marking a pause in the retreat of the Spey glacier during the later glaciation. The head of the loch has been silted up for a long distance by alluvial deltas.

Morsgail.—Rock-basin in Lewisian Gneiss.

Moy.—Ponded by moraines and fluvio-glacial deposits, which were probably laid down against an isolated mass of ice during the retreat of the Findhorn glacier.

Muck.—Probably drift-dammed in hollow along line of Glen Muck fault where it traverses Silurian greywackes and shales.

Muckle Lunga.—Rock-basin in granite.

Muckle Water.—Ponded by drift at head of valley excavated in Middle Old Red flagstones.

Muick.—Simple rock-basin at edge of Lochnagar granite massif. Many Scottish lakes occur in a similar position, probably due to the zone of hornfels which usually surrounds the later granite masses being less tractable than the granite.

Mullardoch.—Valley rock-basin in granulitic schists in Glen Cannich.

Nant.—Rock-basin in Lower Old Red volcanic rocks of the Lorne plateau.

Naver.—Valley rock-basin along the strike of Moine schists, and partly ponded by drift. The hollow in which Loch Naver is situated was one of the outlets for the ice from the Mid-Sutherland area.

Nell.—Lies in hollow partly in the Lorne volcanic plateau, partly in the underlying Lower Old Red sediments, and probably in the floor of schistose rocks on which they rest. The barrier consists of gravels of the 100-ft. raised beach and morainic material, while moraines form islands in the loch. It is therefore highly probable that a lobe of the great confluent glacier which emanated from the Highland glens and crossed part of the Lorne plateau occupied the site of Loch Nell when this beach was being laid down by the sea. Evidences of the retreat of the glacier are abundant in Glen Lonan. The loch has been reduced in size by the deltas of the River Lonan and the Cabrachan Burn.

Ness.—Long U-shaped flat-bottomed rock-basin along the Great Glen fault. The lower end of the loch is ponded by glacial, fluvio-glacial, and raised beach deposits.

North-house.—Rock-basin in altered Old Red Sandstone and intrusive igneous rocks.

Nostarie, an.—Small shallow loch partly in granulitic schists and partly drift-dammed. It is situated on the watershed.

Oban a' Chlachain.—Small tidal loch, partly a rock-basin, in Lewisian Gneiss.

Oban nam Fiadh.—Ponded by drift overlying Lewisian Gneiss and partly tidal.

Obisary.—Complex rock-basin in Lewisian Gneiss, full of strike basins and islands, one of which encloses a small lochan. There are fifteen basins below the 25-ft. contour line, ten below the 50-ft. line, and one below the 75-ft. line. The loch is partly tidal.

Ochiltree.—Ponded by drift resting on Silurian greywackes.

Oich.—Rock-basin along the shatter-belt of the Great Glen, reduced in size by the delta of the Garry. It may be part of the same rock-basin as Loch Lochy, and is separated from it only by drift and alluvium.

Oidhche, na h-.—Valley rock-basin in Torridon Sandstone.

Olavat.—Shallow rock-basin in Lewisian Gneiss.

Ordie.—Partly a rock-basin in schists and partly drift-dammed.

Ossian.—Rock-basin in one of the valleys draining the Rannoch Moor ice-cauldron. The loch is deepest where two lofty mountains approach it on either side, viz. Beinn na Lair (3060 feet) on the north and Cairn Dearg (3084 feet) on the south, the surface of the lake being 1268 ft. above O.D.

Owskeich.—Vol. II. Part I. p. 190.

Pattack.—Partly on rock and partly ponded by drift.

Peerie Water.—Lying in drift.

Peppermill.—Artificial reservoir in boulder clay resting on Upper Carboniferous strata.

Phearsain, a'.—Rock-basin in epidiorites and crystalline schists.

Phitiùlais.—In fluvio-glacial deposits, and ponded by alluvium.

Portmore.—Artificial reservoir in hollow carved out of Silurian greywackes and shales, partly covered by boulder clay.

Poulary.—Narrow valley rock-basin.

Punds Water.—Ponded by drift.

Quoich.—Valley rock-basin in schists, much silted up near the head. Loch na Cuilce (Loch of the Reeds) is a small lochan nearly enclosed by the delta deposits.

Rae.—Partly rock-basin in Torridon Sandstone and partly drift-dammed.

Rannoch.—Vol. II. Part I. p. 137.

Raoinavat.—Rock-basin in Lewisian Gneiss.

Raonasgail.—Rock-basin in Lewisian Gneiss.

Ràth, nan.—Kettle-hole in fluvio-glacial deposits of 100-ft. raised beach.

Ree.—Partly in Silurian greywackes and partly in drift.

Rescobie.—One of a chain of small lochs in the open valley of Strath More, ponded by glacial gravels lying on Lower Old Red Sandstone strata.

Roer.—Rock-basin in crystalline schists.

Rosebery.—Artificial reservoir in gorge cut in drift and Lower Carboniferous strata.

Ruathair, an.—Ponded by drift. It is situated in the wide open valley of Upper Helmsdale, which has been carved out of granulitic schists and granite.

Ruthven.—Rock-basin in crystalline schists on the platform on south-east side of Loch Ness (see Loch Bran).

Sabiston.—Hollow in drift overlying Middle Old Red flagstones.

St John's.—Rock-basin in Caithness flagstones of Middle Old Red Sandstone age. At the outlet the water flows across the shattered strata along the line of the Brough fault, throwing down the Upper Old Red sandstones of Dunnet Head against the flagstones.

St Margaret's.—Artificial loch in Queen's Park, Edinburgh.

St Mary's.—Ponded by alluvium. The lake lies mostly along the strike of Silurian greywackes and is situated in a valley open at the head towards Moffatdale. The Moffat Water, by working along a shatter-belt, has appropriated the highest tributaries of that valley. During the maximum glaciation the ice moved eastward from Moffatdale across the col. The level of St Mary's Loch has been raised by the deltas of the Kirkstead and Dryhope Burns. The Meggat delta has been carried far into the lake, and makes an appreciable feature on its floor. The Loch of the Lowes has been separated from St Mary's Loch by two converging deltas, and the upper end of the former lake has been silted up for some distance up the river Yarrow. The valley above the loch is over-deepened relatively to its tributaries, so that the main river has great difficulty in distributing the material (deltas) brought down by the side streams. All these phenomena point to the action of ice in lowering the gradient of the valley above the foot of the loch.

Sàlach Uidhre, na.—Minor rock-basin in granite and schist, studded with moraines, now covered by the reservoir of Loch Leven Aluminium Works.

Sand.—Ponded by blown sand.

Sandy.—In drift, artificially impounded.

Scadavay.—Irregular rock-basin in Lewisian Gneiss, with numerous strike-basins and rocky islands strewn with glacial debris.

Scamadale.—Valley rock-basin in Lorne volcanic plateau, partly along a line of fault. The loch is partly ponded by morainic and fluvio-glacial deposits, terraces of which occur at intervals along its sides and at the lower end, as if the material had been delivered from the front of the glacier which occupied the site of the loch at the time of their formation.

Scarmclate.—Lying in boulder clay in a wide open valley in Caithness flagstones.

Scaslavat.—Rock-basin in Lewisian Gneiss.

Sealbhag.—Rock-basin in granulitic schists.

Seasgain, an t-.—Rock-basin in Lewisian Gneiss, part of Loch 'Ic Colla.

Seil.—Rock-basin in Lorne volcanic plateau.

Seilich, an t-.—Rock-basin in Moine schists in Glen Tromie.

Setter.—In drift resting on Old Red Sandstone.

Sgamhain.—Rock-basin in Moine schists, the lower end of which has been silted up by the alluvium of Allt Coire Crubaidh, through which the river Carron winds till it reaches the head of the rock gorge at Glencarron. The rock-basin is still further filled with morainic and delta material along its sides and at its head.

Sheallag, na.—Simple valley rock-basin in Lewisian Gneiss, which has been silted up for a mile or two at its head by morainic and fluvio-glacial materials and alluvium.

Shiel.—Rock-basin in schists. Its characteristic straight feature suggests that its long axis coincides with a line of fault. Like most of the western fresh-water lochs, it lies in a deep valley open at both ends, with high mountains on either side. Hence during the glacial period, when the ice-shed was independent of the present watershed, such valleys received a larger volume of ice than could have been obtained from their own catchment basins. It is evident that such was the case with Loch Sheil, for the lake deepens at its head where the valley becomes constricted, and the deep basin is continued till the valley widens at the foot and the lake bends towards the west. A depression of 20 feet would convert Loch Sheil into a typical fiord, and a depression of a little over 50 feet would unite it with Loch Eil and transform the districts of Ardgour, Morvern, and Ardnamurchan into an island. The head of Loch Sheil has been partly silted up by the Finnan and Callop and by the deposits of the 50-ft. beach.

Shin.—Typical valley rock-basin in granulitic Moine schists, with several minor basins, some of which are probably separated by rocky barriers; but one of them is certainly produced by the delta of the river Skiag extending below water nearly across the loch, and forming a favourite fishing-ground. At Shinness the lake branches into Loch Vanavie, a shallow tributary among moraines. Loch Shin lies along the principal outlet from the Mid-Sutherland ice area.

Shurrery.—Partly a rock-basin in Caithness flagstones and partly drift-dammed.

Sior Lochs.—Shallow lochs ponded by drift in hollows of volcanic rocks of the Lorne plateau.

Skae.—Partly in Silurian greywackes and partly drift-dammed.

Skaill.—Rock-basin in Old Red flagstones.

Skealtar.—Rock-basin in Lewisian Gneiss.

Skebacleit.—Rock-basin in Lewisian Gneiss.

Skeen (Annan basin).—Ponded by moraines in corrie or coomb in greywackes and shales (see Sir A. Geikie's *Scenery of Scotland*, 3rd edit., p. 349).

Skene (Dee basin).—Ponded by drift resting upon granite.

Skerrow.—Partly a rock-basin and partly in drift on granite of Cairnsmore of Fleet massif.

Skiach.—Partly in schist and partly drift-dammed.

Skinaskink.—A rock-basin in Lewisian Gneiss and Torridon Sandstone. It contains several minor basins.

Slagain, an t-.—Rock-basin in Torridon Sandstone, partly ponded by drift.

Snarravoe.—Rock-basin in crystalline schists and metamorphic limestones, partly drift-dammed.

Soulseat.—Kettle-hole in fluvio-glacial beds on 100-ft. raised beach.

Spiggie.—Impounded by a barrier of blown sand lying across the mouth of a shallow valley floored by boulder clay, which rests on granite, schist, and Old Red Sandstone. It is separated from Loch Brow by a delta laid down by the Burn of Hill.

SPYNIE.—Shallow lake in raised beach deposits, and probably ponded by the westward-travelling beach which deflects the Lossie westward to Lossiemouth. It was connected with the sea within historic times.

SREINGE, NA.—Rock-basin in schists, limestone, and epidiorite. One side of the lake is traversed by a line of fault along which successive intrusions of basic and acid dykes have been injected and small volcanic vents have been drilled in Tertiary time.

SRÒN SMEUR.—Rock-basin in granite.

STACA, AN.—Ponded by drift. It lies on the watershed of the high plateau between the rivers Morriston and Enrick (Glen Urquhart).

STACK.—Rock-basin in Lewisian Gneiss. It encloses two parallel basins along separate bands of gneiss and foliated granite. The main rock-basin is probably continuous through Loch na h-Ealaidh to Loch More. Loch Stack was formerly much more extensive, as it is surrounded by high terraces of alluvium which are continued down the Laxford for over two miles below the present outlet, and up as far as Loch na h-Ealaidh (see Loch More).

STACSAVAT.—Rock-basin in Lewisian Gneiss.

STAINGE, NA.—Ponded by moraines.

STENNESS.—Tidal loch, only fresh at surface, partly ponded by drift, which probably lies in a rock-basin in the Middle Old Red flagstones. It is separated from Loch Harray by a shallow channel with rocky floor over which the salt water sometimes flows out of Loch Stenness into Loch Harray.

STRANDAVAT.—Hollow in Lewisian Gneiss.

STROM.—Rock-basin along strike of crystalline schists; a tidal loch.

STRUMORE, AN.—Tidal loch.

SUAINAVAL.—Valley rock-basin in Lewisian Gneiss.

SWANNAY.—Ponded by drift resting on Middle Old Red flagstones.

SYRE.—Shallow, irregular lake in moraine drift.

TACHDAIDH, AN.—Vol. II. Part I. p. 353.

TAIRBEIRT STUADHAICH, AN.—Rock-basin in Lewisian Gneiss.

TALLA.—Artificial reservoir in valley excavated in Silurian greywackes and shales. The floor of the valley is covered by boulder clay and alluvium.

TANKERNESS.—In drift which rests upon Middle Old Red flagstones.

TARRUIN AN EITHIR.—Rock-basin in Lewisian Gneiss.

TAY.—Vol. II. Part I. p. 138.

TEÀRNAIT.—Partly in schists and partly in drift.

THOM.—Artificial reservoir probably on site of smaller loch, in Lower Carboniferous rocks of the Renfrewshire plateau.

THREIPMUIR.—Artificial reservoir in forking valley carved out of Lower Carboniferous and Upper Old Red Sandstone strata partly covered by boulder clay.

TILT.—Partly a rock-basin along the line of the Glen Tilt shatter-belt.

The loch is in a through valley between the Tilt and the upper Dee.

Tingwall.—Rock-basin lying along the strike of crystalline schists and metamorphic limestones.

Tollie.—Vol. II. Part I. p. 240.

Tomain, an.—Irregular rock-basin in Lewisian Gneiss, studded with islands (*roches moutonnées*).

Tormasad.—Rock-basin in Lewisian Gneiss.

Tralaig.—Rock-basin in schists and epidiorite, with volcanic rocks of Lorne plateau on each side.

Trealaval.—Irregular, shallow loch, probably a rock-basin in part, lying in Lewisian Gneiss.

Treig.—Rock-basin in schists along the Loch Leven and Loch Etive shatter-belts. It lies in a valley open at both ends, which has been one of the outlets from the Rannoch Moor ice-cauldron.

Trool.—Rock-basin in Lower Silurian greywackes, situated in one of the valleys draining the Galloway ice-cauldron.

Truid air Sgithiche.—Hollow in drift.

Tuirc, an.—Vol. II. Part I. p. 188.

Tulla.—Rock-basin in Moine schist, partly along Loch Laidon shatter-belt. The lake occupies one of the outlet passes from the Moor of Rannoch ice-cauldron, the Orchy having pirated the upper tributaries of the Tay in pre-glacial time. During the retreat of the later glaciers, the outlet valley must have been blocked by ice from the high ground to the west, as there are two terraces of silt which extend far up the valley of the Tulla above the lake. Loch Tulla has been silted up to some extent by tributary streams.

Tummel.—Vol. II. Part I. p. 137.

Turret.—Rock-basin in schistose grits, partly ponded by moraines.

Tùtach.—Kettle-hole in fluvio-glacial deposits.

Uanagan.—Small rock-basin in shatter-belt of Great Glen.

Urigill.—Vol. II. Part I. p. 191.

Urr.—Partly in Silurian greywackes and partly ponded by drift.

Urrahag.—Rock-basin in Lewisian Gneiss.

Ussie.—Vol. II. Part I. p. 290.

Vaara.—Partly a rock-basin in altered Old Red Sandstone strata and intrusive igneous rocks, and partly drift-dammed.

Valtos.—Irregular rock-basin in Lewisian Gneiss.

Vatandip.—Rock-basin in Lewisian Gneiss.

Veiragvat.—Rock-basin in Lewisian Gneiss.

Vennachar.—Vol. II. Part I. p. 49.

Veyatie.—Vol. II. Part I. p. 188.

Voil.—Vol. II. Part I. p. 45.

Vullan, a'.—Hollow in glacial deposits.

Watten.—Shallow loch ponded by boulder clay in wide open valley.

The Caithness flagstones floor a large area of the loch along its northern shore.

WESTER.—Partly in boulder clay, and ponded by blown sand. The sea sometimes enters the loch during exceptionally high tides.

WHINYEON.—Rock-basin in Silurian greywackes and shales.

WHITE (Ryan basin).—Kettle-hole in fluvio-glacial deposits cut off from the Black Loch by the delta of Sheuchan Burn.

WHITE OF MYRTON (Luce basin).—Ponded by drift.

WHITEFIELD.—Ponded by drift.

WOODHALL.—Partly a rock-basin across the strike of Silurian greywackes and shales, and partly in drift.

MAPS

Plate XVI., p. 448. Geological Map of Scotland, giving the broad distribution of the rock-groups, and illustrating the geological section of this paper. The Lewisian Gneiss of the North-West Highlands is distinguished from the metamorphic strata lying between the Moine thrust-plane and the fault along the eastern border of the Highlands. Each of the palæozoic systems, excluding the Permian, is shown by one colour. The Permian and mesozoic strata are together indicated by one colour. The contemporaneous and intrusive igneous rocks of Tertiary time are differently expressed from those of palæozoic age and older date. The important disruptions giving rise to shatter-belts are defined by thick black lines.

Plate XVII., p. 464. Orographical and Bathymetrical Map of Scotland, showing the relief of the land surface and the depth of the surrounding sea. It is introduced for the purpose of comparison with the geological map, to show the relation between the geological structure and the development of the surface contours.

Plate XVIII., p. 474. Map showing Direction of Ice-flow and Probable Ice-front in North-West Europe during Maximum Glaciation. It indicates the main centres of ice-dispersion in Scotland during the climax of glacial conditions, the union of the local ice-sheets with that of Scandinavia, the probable path of the combined ice-field across the Continental Shelf, and the conjectural ice-front along the Atlantic and Arctic Rise.

THE CHARACTERISTICS OF LAKES IN GENERAL, AND THEIR DISTRIBUTION OVER THE SURFACE OF THE GLOBE

By Sir JOHN MURRAY, K.C.B., F.R.S., D.Sc., etc.

CONTENTS

INTRODUCTION

Although this work deals specially with the fresh-water lochs of Scotland, still it seems desirable to review briefly the distribution and peculiarities of lakes in general. The Scottish lakes are all in a region which has in recent geological times been covered by an ice-sheet. By way of contrast it will be interesting to look at the lakes in other similarly glaciated regions, and at lake regions where there is no evidence that ice has played any part in the formation of the lakes.

Definition. The generally accepted definition of a lake is a mass of still water situated in a depression of the ground not continuous with the ocean. The term is sometimes applied to widened parts of a river, and sometimes to bodies of fresh or brackish water which lie along sea-coasts at sea-level, and may even be in direct communication with the sea. In English, the terms *pond*, *tarn*, *loch*, *mere*, and *salt-pan* are applied to smaller bodies of water according to their size and position on the land-surfaces. The science dealing with the study and description of lakes is called Limnology[1] and Limnography.

Distribution.

Lakes are nearly universally distributed. They are sometimes so large that an observer cannot see objects situated on the opposite shore, owing to the surface of the lake assuming the general curvature of the earth's surface; but the vast majority are of relatively small size. They occur at all altitudes; some large lakes in Tibet are 15,000 feet above the level of the sea, while the Dead Sea is 1268 feet below sea-level. They also vary greatly in depth and volume of water.

Source of water.

In describing the Scottish fresh-water lochs they have been arranged according to the river basins in which they are situated, for it has been found that lakes are in a very special manner associated with the drainage areas and river systems of the globe. The primary source of lake-water is atmospheric precipitation, which may reach the lakes through rain, springs, rivers, melting ice and snow, and the immediate run-off from the land-surfaces. This water contains substances both in suspension and solution. The suspended matter is deposited for the most part on the bed of the lake, and the matter in solution is borne to the ocean, or accumulates in the lakes situated in the lowest reaches of inland drainage areas.

Precipitation and evaporation.

In catchment basins where precipitation exceeds evaporation the lakes have an outlet, and the outflowing rivers pour their waters ultimately into the ocean. The water in the lakes of these catchment basins is continually being renewed, consequently the salts in solution do not accumulate; the water is drinkable, and the lakes are called fresh-water lakes.

In catchment basins where evaporation exceeds precipitation—which is the case in all inland drainage areas—the running water of the system does not reach the ocean. In consequence, while the lakes in the higher reaches of an inland drainage area have outlet rivers, and their waters are fresh and drinkable, the salts in solution in the lakes towards the lower portions of these catchment basins accumulate and render the water undrinkable; hence we find in these situations what are called salt lakes.[2]

[1] λίμνη, a lake; λόγος, a discourse. The word "limnography" is used sometimes in discussions of the variations in the level of lakes as shown by the limnograph.

[2] It is to be understood that here and in the sequel the word "salt" connotes not merely common salt, viz. sodium chloride, but any compound of an inorganic

Genetic relationship.

In areas which have relatively recently been raised above the sea, and in areas which have recently been covered with an ice-cap, the river systems are young or adolescent, and lakes are numerous. Through the action of the ordinary agencies of disintegration and denudation lakes continually tend to disappear, their outlets being cut down, and their basins being filled up with detrital matter and organic growths. Hence in mature river basins there are relatively few lakes, unless the river system has been rejuvenated by mountain growth.[1]

base with an inorganic acid ; that is, the word "salt" comprises such compounds as calcium carbonate, sodium sulphate, magnesium chloride, etc., whilst sodium chloride will be referred to as such or as "common salt." Similarly, the words "saline" and "salinity" are to be understood as applying to total dissolved solids and not to an individual salt, whether sodium chloride or any other. As regards the term "alkaline," it will suffice for present purposes to define alkaline waters as those which hold an excess of sodium carbonate (with more or less potassium carbonate) in solution.

[1] This genetic history of lakes and river basins is well outlined by Professor Davis in the following extracts (*Science*, vol. x. pp. 142–143, 1887):—

"When a new land rises from below the sea, or when an old land is seized by active mountain-growth, new rivers establish themselves upon the surface in accordance with the slopes presented, and at once set to work at their long task of carrying away all of the mass that stands above sea-level. At first, before the water-ways are well cut, the drainage is commonly imperfect: lakes stand in the undrained depressions. Such lakes are the manifest signs of immaturity in the life of their drainage system. We see examples of them on new land in Southern Florida ; and on a region lately and actively disturbed in Southern Idaho, among the blocks of faulted country described by Russell. But as time passes, the streams fill up the basins and cut down the barriers, and the lakes disappear. A mature river of uninterrupted development has no such immature features remaining. The life of most rivers is, however, so long, that few, if any, complete their original tasks undisturbed. Later mountain-growth may repeatedly obstruct their flow; lakes appear again, and the river is rejuvenated. Lake Lucerne is thus, as Heim has shown, a sign of local rejuvenation in the generally mature Reuss. The head waters of the Missouri have lately advanced from such rejuvenation; visitors to the National Park may see that the Yellowstone has just regained its former steady flow by cutting down a gate through the mountains above Livingston, and so draining the lake that not long ago stood for a time in Paradise Valley. The absence of lakes in the Alleghany Mountains, that was a matter of surprise to Lyell, does not indicate any peculiarity in the growth of the mountains, but only that they and their drainage system are very old.

"The disappearance of original and mountain-made lakes is therefore a sign of advancing development in a river. Conversely, the formation of small shallow lakes of quite another character marks adolescence and middle life. During adolescence, when the head-water streams are increasing in number and size, and making rapid conquest of land-waste, the lower trunk-stream may be overloaded with silt, and build up its flood-plain so fast that its smaller tributaries cannot keep pace with it: so the lakes are formed on either side of the Red River of Louisiana, arranged like leaves on a stem ; the lower Danube seems to present a similar case. The flood-plains of well-matured streams have so gentle a slope

From this point of view it will be at once evident that rivers are frequently older than the present topography of the land-surfaces; they can often cut their way through folds of the crust as rapidly as these arise across their course. It is equally evident, on the other hand, that lakes must be regarded as but transient features of the ever-changing surface of the earth. They come and go, arise and become extinguished with the varying cycles of topographic development, and with the climatic changes of the regions in which they are located.

Temperature.

The temperature of the water in lakes varies with the latitude and with the altitude. It is subject to much variation, depending on the depth, the mass of water, and the superficial area of the lake, that is, the extent of surface exposed to the sun and sky. The

that their channels meander through great curves. When a meander is abandoned for a cut-off, it remains for a time as a crescentic lake. When rivers get on so far as to form large deltas, lakes often collect in the areas of less sedimentation between the divaricating channels. Deltas that are built on land, where the descent of a stream is suddenly lessened and its enclosing valley-slopes disappear, do not often hold lakes on their own surface; for their slope is, although gentle, rather too steep for that: but they commonly enough form a lake by obstructing the stream in whose valley they are built. Tulare Lake in southern California has been explained by Whitney in this way.

"The contest for drainage area that goes on between streams heading on the opposite slopes of a divide sometimes produces little lakes. The victorious stream forces the divide to migrate slowly away from its steeper slope, and the stream that is thus robbed of its head waters may have its diminished volume clogged by the fan-deltas of side-branches farther down its valley. Heim has explained the lakes of the Engadine in this way. The Maira has, like an Italian brigand, plundered the Inn of two or more of its upper streams, and the Inn is consequently ponded back at San Moritz and Silvaplana. On the other hand, the victorious stream may by this sort of conquest so greatly enlarge its volume, and thereby so quickly cut down its upper valley, that its lower course will be flooded with gravel and sand, and its weaker side-streams ponded back. No cases of this kind are described, to my knowledge, but they will very likely be found; or we may at least expect them to appear when the northern branches of the Indus cut their ways backwards through the innermost range of the Himalaya, and gain possession of the drainage of the plateaus beyond; for then, as the high-level waters find a steep outlet to a low-level discharge, they will carve out cañons the like of which even Dutton has not seen, and the heavy wash of waste will shut in lakes in lateral ravines at many points along the lower valleys.

"In its old age, a river settles down to a quiet, easy, steady-going existence. It has overcome the difficulties of its youth, it has corrected the defects that arose from a period of too rapid growth, it has adjusted the contentions along the boundary-lines of its several members, and has established peaceful relations with its neighbors: its lakes disappear, and it flows along channels that meet no ascending slope on their way to the sea.

"Certain accidents to which rivers are subject are responsible for many lakes. Accidents of the hot kind, as they may be called for elementary distinction, are influence of the winds in producing currents, and the greater or less abundance of salts in solution, also affect the temperature conditions, as well as the quantity of atmospheric gases absorbed from the air at the surface and distributed by currents and convection throughout the mass of water in the lake.

Deposits. The deposits in lakes consist of gravels, sands, marls, clays, and muds, the variations in these depending largely on the geology of the country in which the lakes are situated. Usually the muds in the deeper parts of lakes contain a large amount of organic matter, which is chiefly of vegetable origin, and in this respect they differ from marine deposits. It occasionally happens that diatomaceous deposits are formed in lakes, especially where the detrital matter from the

seen in lava-flows, which build great dams across valleys: the marshes around the edge of the Snake River lava-sheets seem to be lakes of this sort, verging on extinction: crater lakes are associated with other forms of eruption. Accidents of the cold kind are the glacial invasions: we are perhaps disposed to overrate the general importance of these in the long history of the world, because the last one was so recent, and has left its numerous traces so near the centres of our civilization; but the temporary importance of the last glacial accident in explaining our home geography and our human history can hardly be exaggerated. During the presence of the ice, especially during its retreat, short-lived lakes were common about its margin. . . . We owe many prairies to such lakes. The rivers running from the ice-front, overloaded with sand and silt, filled up their valleys and ponded back their non-glacial side-streams; their shore-lines have been briefly described in Ohio and Wisconsin, but the lakes themselves were drained when their flood-plain barriers were terraced; they form an extinct species, closely allied to the existing Danube and Red River type. As the ice-sheet melts away, it discloses a surface on which the drift has been so irregularly accumulated that the new drainage is everywhere embarrassed, and lakes are for a time very numerous. Moreover, the erosion accomplished by the ice, especially near the centres of glaciation, must be held responsible for many, though by no means for most, of these lakes. Canada is the American type, and Finland the European, of land-surface in this condition. The drainage is seen to be very immature, but the immaturity is not at all of the kind that characterized the first settlement of rivers on these old lands: it is a case, not of rejuvenation, but of regeneration; the icy baptism of the lands has converted their streams to a new spirit of lacustrine hesitation unknown before. We cannot, however, expect the conversion to last very long: there is already apparent a backsliding to the earlier faith of steady flow, to which undisturbed rivers adhere closely throughout their life.

"Water-surface is, for the needs of man, so unlike land-surface, that it is natural enough to include all water-basins under the single geographic term 'lakes.' Wherever they occur,—in narrow mountain-valleys or on broad, level plains; on divides or on deltas; in solid rock or in alluvium,—they are all given one name. But if we in imagination lengthen our life so that we witness the growth of a river-system as we now watch the growth of plants, we must then as readily perceive and as little confuse the several physiographic kinds of lakes as we now distinguish the cotyledons, the leaves, the galls, and the flowers, of a quickly growing annual that produces all these forms in appropriate order and position in the brief course of a single summer."

adjoining land is small in quantity. In salt lakes, again, there may be a chemical precipitation of salts on the floor of the lakes.

In addition to a rise and fall of the surface of the lake due to the varying amount of rainfall in the region, there may be a rise at one end of a lake produced by the heaping up of water through strong winds and gales, and, in addition to the ordinary waves, standing waves, called seiches, have been detected in most lakes. At the boundary-line separating layers of water of different temperature and density, what are called "temperature seiches" have been discovered in the Scottish and other lakes. Motions.

Lakes are inhabited by a great variety of organisms, but both species and genera are much less numerous than in the ocean, and some whole classes—the Echinoderms, for example—are unrepresented. The ocean was almost certainly the original home of living beings, and relatively few species have been able to establish themselves in the less congenial fresh water.[1] In very deep lakes the bottom fauna is represented by only a few species, or life may be wholly absent, with the exception of bacteria. In temperate regions there appears to be active vertical circulation of the water, even in the deepest lakes, at least twice a year, when the maximum density point (39°·1 F., 4° C.) is reached at the surface. In tropical regions, however, it is probable that, owing to an absence of, or much less active, vertical circulation, there may be insufficient oxygen to support animal life at the bottom of very deep lakes. There is a well-marked cosmopolitanism in the plankton organisms of lakes. Indeed, the freshwater plankton is regarded as the oldest community of organisms on the earth. Organisms.

Lakes may be compared to oceanic islands. Just as an oceanic island presents many peculiarities in its rocks, soil, fauna, and flora, due to its isolation from the masses of continental land, so does a lake present individuality and special peculiarities in its physical, chemical, and biological features, owing to its position with reference to the drainage from the surrounding land, and its separation from the mass of waters represented by the great oceans. Compared with oceanic islands.

The surface of the earth, with which we are daily in direct contact, is composed of lithosphere, hydrosphere, and atmosphere, and these all interpenetrate. Lakes, rivers, underground water, the water of hydration in the lithosphere, and the water-vapour of the atmosphere, must all be regarded as belonging to outlying portions of the hydrosphere, which consists mainly of the waters of the great ocean basins. Hydrosphere.

Lakes may be classified in a great variety of ways, but no method

[1] R. Quinton, *L'eau de mer milieu organique*, Paris, 1904.

of classification which has yet been proposed can be regarded as completely satisfactory.

Classification by physical characters.

Lakes have been arranged according to:—

(1) Their superficial area.
(2) Their cubic contents of water.
(3) Their depth.
(4) Their latitude.
(5) Their elevation above or below sea-level.
(6) Their being salt or fresh.

All these classifications must be regarded as more or less artificial. Some of the principal lakes, arranged according to these methods, will be found at the end of this paper.

Classification by temperature.

Another system is to arrange lakes according to their temperature conditions. For instance, Forel divides lakes into three types—polar, temperate, and tropical—and bases the distinction upon bottom temperatures as follows:—

(1) Tropical type: temperature of deep layers varies from and above that of maximum density.
(2) Temperate type: temperature of deep layers varies above and below that of maximum density.
(3) Polar type: temperature of deep layers varies from and below that of maximum density.

He subdivides each type into two classes, deep and shallow, defining deep lakes as those which have a constant bottom temperature, and shallow lakes as those which have a variable bottom temperature.

George C. Whipple, in a paper in the *American Naturalist*, 1898, on "Classification of Lakes according to Temperature," suggests that lakes be divided into three types according to their surface temperatures, and into three orders according to their bottom temperatures.[1] These three types are:—

(1) Polar type: surface temperature never above that of maximum density.
(2) Temperate type: surface temperature sometimes above and sometimes below that point.
(3) Tropical type: surface temperature never below that of maximum density.

This division into types corresponds somewhat closely with geographical location.

His three orders may be defined as follows:—

(*a*) Lakes of the first order have bottom temperatures practically constant at or near the point of maximum density.

[1] See note by E. M. Wedderburn on p. 144.

(*b*) Lakes of the second order have bottom temperatures practically constant, but undergoing annual fluctuations.

(*c*) Lakes of the third order have bottom temperatures seldom very far from the surface temperatures.

This division into orders corresponds in a general way to the characters of lakes—*i.e.* size, bulk of water, depth—and to the climate of the surrounding country.

In Scotland lakes are sometimes divided into those which are covered with ice in winter, and those which never freeze over, the former being shallow lakes with a high annual range of temperature, and the latter deep lakes with a low annual range of temperature.

The most generally adopted method of classification of lakes in the past is one based on their origin, chiefly from the geological point of view:— Classification by origin.

1. **Rock-Basins.**—These have been formed in several ways:—

(a) *By slow movements of the earth's crust*, during the formation of mountains; the Lake of Geneva in Switzerland and the Lake of Annecy in France are due to the subsidence or warping of part of the Alps; on the other hand, Lakes Stefanie, Rudolf, Albert Nyanza, Tanganyika, Leopold,[1] and Nyasa, in Africa, and the Dead Sea in Syria, are all believed to lie in a great rift or sunken valley.

(b) *By volcanic agencies.*—Crater-lakes formed on the sites of dormant volcanoes may be from a few yards to several miles in width, have generally a circular form, and are often without visible outlet. Excellent examples of such lakes are to be seen in the province of Rome (Italy), and in the central plateau of France, where M. Delebecque found the Lake of Issarlès 329 feet in depth. The most splendid crater-lake is found on the summit of the Cascade Range of Southern Oregon (U.S.A.). This lake is 2000 feet in depth.

(c) *By solution and subsidence due to subterranean channels and caves in limestone rocks.*—When the roofs of great limestone caves or underground lakes fall in, they produce at the surface what are called *limestone sinks.* Lakes similar to these are also found in regions abounding in rock-salt deposits; the Jura Range offers many such lakes.

(d) *By glacier erosion.*—A. C. Ramsay has shown that innumerable lakes of the northern hemisphere do not lie in fissures produced by underground disturbances, nor in areas of subsidence, nor in synclinal folds of strata, but are the results of glacial erosion. Many flat alluvial plains above gorges in Switzerland, as well as in the Highlands of Scotland, were, without doubt, what Sir Archibald Geikie calls glen-lakes, or true rock-basins, which have been filled up by sand and mud brought into them by their tributary streams.

[1] Also called Rukwa, Hikwa, or Likwa.

2. **Barrier Basins.**—These may be due to the following causes:—

(a) *A landslip* often occurs in mountainous regions, where strata, dipping towards the valley, rest on soft layers; the hard rocks slip into the valley after heavy rains, damming back the drainage, which then forms a barrier-basin. Many small lakes high up in the Alps and Pyrenees are formed by a river being dammed back in this way.

(b) *A glacier.*—In Alaska, in Scandinavia, and in the Alps, a glacier often bars the mouth of a tributary valley, the stream flowing therein is dammed back, and a lake is thus formed. The best-known lake of this kind is the Märjelen Lake in the Alps, near the great Aletsch Glacier. The lake varies in area, being sometimes a mile in length, and at other times disappearing entirely through a crevasse in the ice; in August 1907 it disappeared in one night. Lake Castain in Alaska is barred by the Malaspina Glacier; it is two or three miles long and a mile in width when at its highest level, and discharges through a tunnel nine miles in length beneath the ice-sheet. The famous parallel roads of Glen Roy in Scotland are successive terraces formed along the shores of a glacial lake during the waning glacial epoch. Lake Agassiz, which during the glacial period occupied the valley of the Red River, and of which the present Lake Winnipeg is a remnant, was formed by an ice-dam along the margin of two great ice-sheets. It is estimated to have been 700 miles in length, and to have covered an area of 100,000 square miles, thus exceeding the total area of the five great North American lakes: Superior (31,200 square miles), Michigan (22,450 square miles), Huron with Georgian Bay (23,800 square miles), Erie (9960 square miles), and Ontario (7240 square miles).

(c) *The lateral moraine of an actual glacier.*—These lakes sometimes occur in the Alps of Central Europe and in the Pyrenees.

(d) *The frontal moraine of an ancient glacier.*—The barrier in this case consists of the last moraine left by the retreating glacier. Such lakes are abundant in the northern hemisphere, especially in Scotland and the Alps.

(e) *Irregular deposition of glacial drift.*—After the retreat of continental glaciers great masses of glacial drift are left on the land-surfaces; but, on account of the manner in which these masses were deposited, they abound in depressions that become filled with water. What are called "kettle-holes" are evidently spaces originally filled by large masses of ice, which melted away after the detrital matter was laid down. Often these lakes are without visible outlet, the water frequently percolating through the glacial drift. These lakes are so numerous in the north-eastern part of North America, that one can trace the southern boundary of the great ice-sheet by following the southern limit of the lake-strewn region, where lakes may be counted by tens of thousands, varying from the size of a tarn to that of the great Laurentian lakes above mentioned. A good example of this is found in Scotland in the Red Lochan at Tulloch.[1]

(f) *Sand drifted into dunes.*—It is a well-known fact that sand may travel across a country for several miles in the direction of the prevailing winds. When these sand-dunes obstruct a valley a lake may be formed; a good example of such a lake is found in Moses Lake in the State of Washington. The sand-dunes may also fill up or submerge river-valleys and lakes—for instance, in the Sahara, where the Shotts are vast lakes filled with sand and water near the point of saturation. Indeed, in the afternoon, owing to evaporation, the surface is covered with salt crystals. In the morning these have all deliquesced, and the surface looks like an ordinary lake.

(g) *Alluvial matter deposited by lateral streams.*—If the current of a main river be not powerful enough to sweep away detrital matter brought down by a lateral stream, a dam is formed, causing a lake. These lakes are frequently met with in the narrow valleys of the Highlands of Scotland.

(h) *Flows of lava.*—Lakes of this kind are met with in volcanic regions. The marshes round the edges of the Snake River lava-sheets seem to be lakes of this sort verging on extinction. In Auvergne, a small basin, the Lac d'Aidat, is enclosed by lava from the extinct Puy de la Vache, and the Lac de Chambon was formed by the eruption of volcanic cones in its valley. The Sea of Tiberias seems to be held back by a lava-stream that entered the valley of the Jordan from the east. Lake Assal, at the head of the Gulf of Aden, is shut in by a bed of lava.

3. **Organic Basins.**—In the vast tundras that skirt the Arctic Ocean in both the Old and the New World, a great number of frozen ponds and lakes are met with, surrounded by banks of vegetation. Snow-banks are generally accumulated every season at the same spots. During summer the growth of the tundra vegetation is very rapid, and the snow-drifts that last longest are surrounded by luxuriant vegetation. When such accumulations of snow finally melt, the vegetation on the place they occupied is much less than along their borders. Year after year such places become more and more depressed, comparatively to the general surface, where vegetable growth is more abundant, and thus give origin to lakes. The obstructions formed by the "sudd" of the Upper Nile region, and by the "beaver dams" of the North American rivers, may be considered as giving rise to lakes of organic origin.

It is well known that in coral-reef regions small bays are cut off from the ocean by the growth of corals, rain and river waters accumulate behind these barriers, fresh-water basins being thus

[1] See vol. ii. part i. p. 375.

ultimately formed. A similar process produces lakes along continental shores through the formation of sand-dunes or accumulation of shingle, as, for instance, in Florida.

4. **Wind-formed Basins.**—The wind travelling in a cyclonic manner across plains often lifts the sand and earth, carrying them away, and thus forming shallow basins. Many of the shallow lake-pans of desert regions are believed to have been formed in this way, as well as lakes where sand-dunes are numerous.[1]

When a quite comprehensive view is taken of the land-surfaces of the globe, two regions may be distinguished:

Two distinct Lake Regions.

(A) The region of INLAND DRAINAGE AREAS, where evaporation exceeds precipitation, situated in the desert regions of the globe.

(B) The region of DRAINAGE AREAS, THE WATERS FROM WHICH FLOW DIRECTLY INTO THE OCEAN, where precipitation exceeds evaporation, situated in the well-watered regions of the globe with abundant vegetation. The water of lakes associated with the former class (A) may be either salt or fresh; that of lakes associated with the latter class (B) is always fresh.

In reviewing the distribution of lakes over the surface of the globe the order here suggested will be adopted in this paper.

LAKES CONNECTED WITH INLAND DRAINAGE AREAS

Distribution of inland drainage areas.

The inland drainage areas are situated in two belts running right round the world, the one in the northern hemisphere, approximately between the latitudes of 30° and 50° North, the other in the southern hemisphere, approximately between the latitudes of 20° and 30° South. These regions correspond so closely with the great desert regions and with the salt-lake areas, where there is an annual rainfall of less than 10 inches, that the relation is evidently one of cause and effect. In the northern belt are the lakes of the Gobi Desert, the Sea of Aral, the Caspian Sea, the Dead Sea, the arid desert of Arabia, the lakes of the Sahara Desert, and of the Great Salt Lake and Alkali Deserts of the Rocky Mountains in North America. In the southern belt are the arid regions of the interior

[1] Sir John Lubbock, in his book *The Scenery of Switzerland*, p. 203, divides the lakes into the following four classes:—

(1) Lakes of embankment.
(2) Lakes of excavation.
(3) Lakes of subsidence.
(4) Crater lakes.

In the year 1883 Professor W. M. Davis published a classification of lakes according as they were made by constructive, destructive, or obstructive processes (see *Proc. Boston Soc. Nat. Hist.*, vol. xxi. p. 315, 1883).

of Australia, the Kalahari Desert of Africa, and the Atakama Desert of South America. These inland drainage areas are estimated by Murray[1] to occupy 11,486,000 English square miles, or about three-seventeenths of the total land-surface of the globe.

It was shown by very numerous observations during the *Challenger* Expedition that in the open ocean far from land the daily fluctuations of temperature in the surface waters do not exceed one degree Fahrenheit. Hence the atmosphere over the ocean may be said to rest on a surface the temperature of which is practically uniform at all hours of the day. This is in striking contrast to what obtains on land-surfaces towards the centres of the continental masses, where the air is often dry, and solar and terrestrial radiation produce a very wide daily range of temperature, possibly one hundred degrees Fahrenheit from 3 p.m. to 3 a.m. In the temperature conditions here indicated we have one of the prime factors of meteorology,—a factor which determines the position of the great permanent anticyclonic areas over the oceans. Air with a large quantity of water-vapour absorbs more of the sun's rays, becomes in consequence more heated, and is specifically lighter than dry air; hence moist air ascends in cyclonic areas, is deprived of its moisture in ascending, becomes cool, and spreading laterally descends as heavy dry cool air in anticyclonic areas. The redistribution of the mass of the atmosphere is brought about in this manner. Numerous observations show that winds are simply the movements of the atmosphere that set in from where there is a surplus to where there is a deficiency of air. Isobaric maps and maps showing the prevailing winds are in accordance with each other.

Now, the two belts of inland drainage areas and low rainfall above referred to are likewise the regions of high annual atmospheric pressure, which pass in two belts completely round the globe. The belt of high pressure in January in the northern hemisphere broadens as it passes over land and contracts as it crosses over the ocean. Its greatest breadth is over Asia, and its least over the Pacific, that is, where land and ocean attain respectively their maximum dimensions. Similar relations exist in the southern hemisphere. In the *winter months* of each hemisphere these areas on land are occupied by anticyclones, in which heavy, dry, cold air descends and flows out on the surface all round. In the *summer months* of each hemisphere these same areas become cyclonic, and the winds are drawn in at the surface from surrounding regions and are deprived of their moisture before reaching the centre of the desert regions, where they ascend as warm currents to the higher regions of the atmosphere.

The primary cause of the rainless, desert, salt-lake, and inland

[1] See *Scott. Geogr. Mag.*, vol. ii. p. 552, 1886.

drainage areas may, then, be traced to the fact that they are situated in those regions of the earth's surface where the prevailing winds blow from colder to warmer latitudes, and from off land and not directly from off the ocean. The distribution of salt lakes may consequently be said to depend more on meteorological than on topographical or geological phenomena. These meteorological conditions have also a very marked influence on vegetable, animal, and human life, as well as on the geological strata now in process of formation.

Should the climate in the neighbourhood of these inland drainage areas change and the rainfall become more abundant, the salt lakes would slowly increase in size, and would ultimately find an outlet by means of a river to the ocean at the lowest part of the rim of the basin. What was once a small salt lake would gradually become a large fresh-water lake, pouring its waters directly into the ocean through a river. It is most probable that this has frequently occurred in the past history of the earth, but traces of the change have been wholly obliterated, or are now difficult to detect. Numerous instances of the contrary process, where large fresh-water lakes have been converted in recent geological times into salt lakes, are to be observed in many inland drainage areas. Instances of this nature will be pointed out in the following pages. In some desert regions both the river channels and the lakes are completely filled up with blown sand. The artesian wells along the course of the Oued Rhir in the Sahara often throw up fresh-water fishes and crustaceans, thus indicating a buried river. The lakes of inland drainage areas may be, as previously stated, either fresh or salt. The higher lakes, having an outflowing river, remain fresh and drinkable, while the salts which are leached out of the surrounding land all accumulate in the lowest lake of the series, the salts in solution varying both in quantity and composition in each locality.

In the following pages we shall in the first instance refer to the inland drainage areas of the northern hemisphere, and then to those of the southern hemisphere.

Northern Hemisphere.

Eural-Asia.

The largest inland drainage area is that of central Eural-Asia, which occupies, according to Murray, 4,785,000 English square miles, and stretches from about long. 35° to 125° E., and from lat. 25° to 60° N. (see fig. 63). It includes the lakes of the Aralo-Caspian depression, the lakes of the Gobi Desert, Lake Hámun in the Seistan depression between Afghanistan and Persia, Lake Urmi on the Persian plateau, and Lake Van in Eastern Anatolia.

The greater part of Central Asia is occupied by two high plateaus: a western one extending in a south-eastern direction from the Black Sea to the valley of the Indus, and an eastern one stretching from the Himalayas to the north-eastern extremity of Asia.

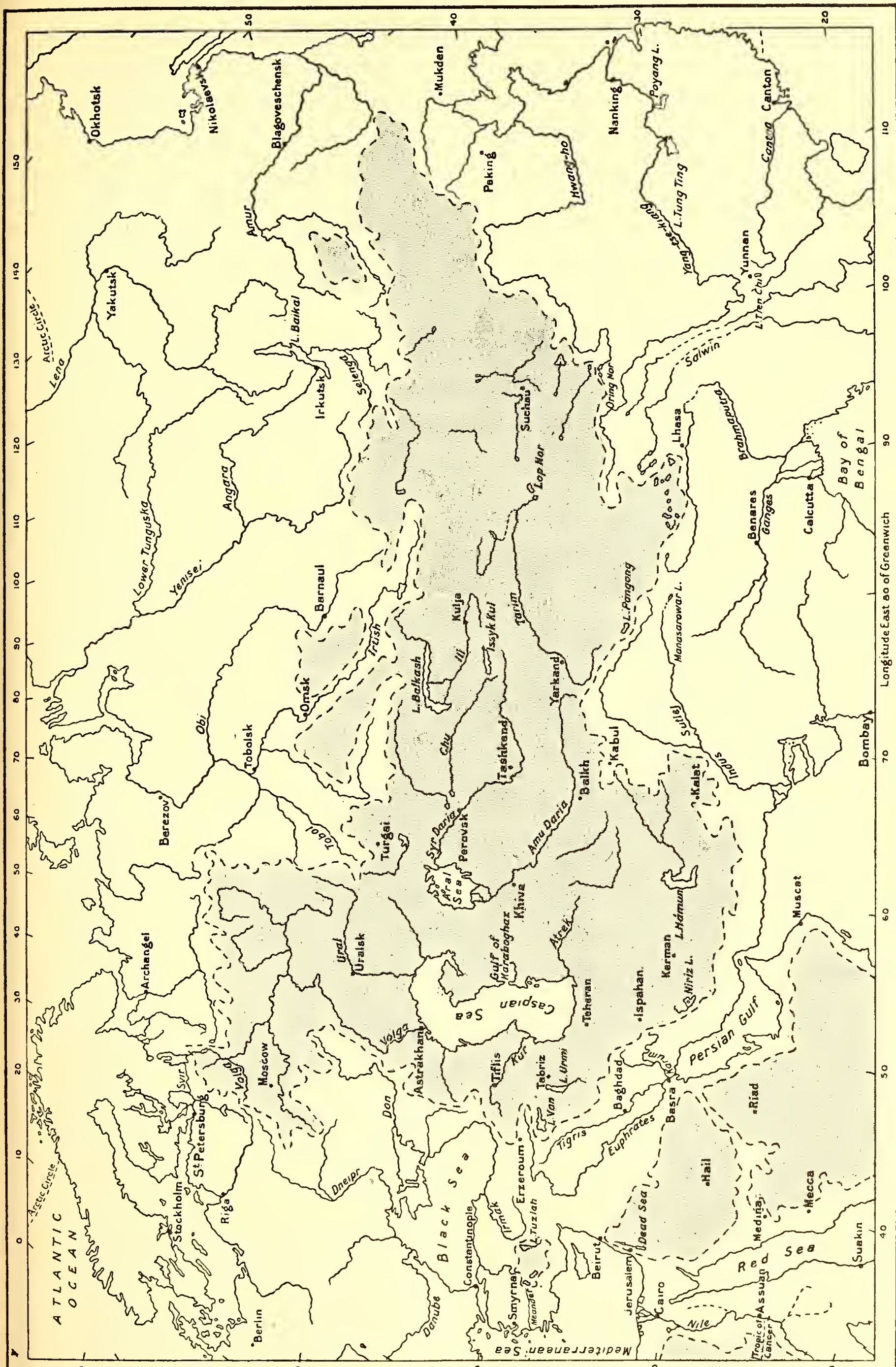

FIG. 63.—Inland Drainage Areas of Eural-Asia.
[The inland drainage areas are stippled.]

These plateaus separate the lowlands of Siberia and the Aralo-Caspian depression from the lowlands of Mesopotamia, India, and China to the south, and together with the Aralo-Caspian depression form most of the inland drainage area of the continent. The lower terrace of the eastern plateau, which is occupied by Eastern Turkestan in the west and by the Desert of Gobi in the east, is known as the Central Asian depression; but as its altitude varies from 3000 to 4000 feet in the highest part to 2200 feet in the lowest—the depression of Lob Nor—the term must be taken as purely relative to the height of the surrounding plateau.

It has long been surmised by historians that certain parts of Asia have been growing more arid, and the phrase, "the desiccation of Asia," has been much used in this connection. But while some employ it to denote the process of change[1] from the coldness or moisture of the Glacial period to the comparative aridity of the geological epoch of to-day, and maintain that this process is accelerated by that gradual elevation of parts of the continent which led to the separation of the Tertiary inland seas, and which is still in progress at the present time,[2] others take it as meaning a gradual change in climate supposed to have taken place during the period covered by history. Brückner,[3] from a study of meteorological records and of the fluctuations in the level of the Caspian and other isolated lakes, comes to the conclusion that the variations of climate form a cycle of thirty-five years. Woeikoff,[4] basing his reasoning on recent Russian investigations on Central Asian lakes, such as those of Berg on the Sea of Aral, and on the examination of the meteorological records for the town of Barnaul in Western Siberia, for which a longer series is available than for any other Asiatic station, adopts the theory that if variations are recurrent the period must extend over at least sixty years; but as records of meteorological observations date back little more than one hundred years the precise length cannot be determined for some considerable time. Central Asia he considers to have just passed through a minimum phase. Ellsworth Huntington[5] holds that, between the recurrent glacial epochs at one end of the scale and the climatic variation at the other there is an intermediate pulsation, the beats of which are to be reckoned by thousands of years and will be coincident with regular fluctuations of rainfall and temperature throughout the world.

[1] Kropotkin, "The Desiccation of Eur-Asia," *Geogr. Journ.*, vol. xxiii. p. 724, 1904.

[2] Kropotkin, "The Orography of Asia," *Geogr. Journ.*, vol. xxiii. p. 346, 1904.

[3] *Klimaschwankungen seit 1700*, Wien, 1890.

[4] "Der Aral See und sein Gebiet nach den neuesten Forschungen," *Petermann Mitt.*, Bd. lxv. p. 82, 1909.

[5] *The Pulse of Asia*, London, 1907.

Aralo-Caspian basin.

The Aralo-Caspian basin is bounded by the Caspian on the west, the plateaus of Persia and Afghanistan on the south, and the Pamirs on the east, stretching to the Thian-Shan and the Tarbagati on the north-east, to Siberia on the north, and merging on the north-west into the steppes which lie between the Ural and the Caspian. On one side the mountains rise to heights of from 20,000 to 23,000 feet, while on the other side the surface sinks to the Caspian, about 86 feet below the level of the sea.

The fluctuations of level in the Caspian Sea during historic times, and its relation to the Sea of Aral and the Amu Daria (Oxus of the ancients, and Jihun of the Arabs), have caused much discussion among modern writers.[1] Strabo, the Greek geographer, quotes Aristobulus, the geographer of Alexander the Great, as saying that in the fourth century before Christ the traffic from India came down the Oxus River to the Caspian, into which sea the river flowed. A little later, about 300 B.C., Patrocles, the admiral of Seleucus, made a survey of the southern coast of the Caspian, and reported that the Oxus and Jaxartes (Syr Daria) Rivers both entered that sea, the mouth of the one being 240 miles from that of the other. Under present conditions the Oxus and Jaxartes could not possibly enter the Caspian Sea by separate mouths, but were the level of the Caspian very much higher than it is now, that sea would almost coalesce with the Sea of Aral, and conditions would then agree with the description of Patrocles. Physiographic evidence which seems to show that this was at one time the case is given by the abandoned shore-lines that border the Caspian at various heights up to 600 feet above the present water-level. These indicate by their weak development that the sea did not stand at any one level for a long time. Istakhri, who visited the region about 920 A.D., said that the Aral received the Oxus, the Jaxartes, and several other rivers. Edrisi (A.D. 1154) speaks of the Aral as a "well-known lake," and confirms most of what Istakhri says. He also shows in his map the Jihun flowing into the Aral Sea.[2] Professor Woeikoff[3] shows that a rise of the River Amu Daria of only 4 metres (13 feet) above the level of 1901 would cause an overflow of part of its waters by the Usboi to the Caspian, one effect of which would be that the Sea of Aral would become a fresh-water lake. Historical evidence goes to show that from the thirteenth to the end of the

[1] Humboldt, *Asie centrale*, Paris, 1843; Rawlinson, "Note on the Oxus River," *Proc. Roy. Geogr. Soc.*, vol. xi. p. 114, 1866–67; Brückner, *Klimaschwankungen seit 1700*, Wien, 1890.

[2] Aitoff's reduction of the maps of Edrisi's Geography in Schrader's *Historical Atlas*, Carte 24, Paris, 1896.

[3] *Op. cit.*, p. 84.

sixteenth centuries this overflow actually occurred, and it would appear that this was a period of comparatively high rainfall in Eastern Europe and Western Asia. As far as may be judged from the evidence that has been collected, it seems that from about 400 B.C. to 400 A.D. the climate of the Aralo-Caspian basin was damper and cooler than now. From 400 to 800 A.D. there was a transition to a warmer or drier epoch than that of to-day; this was succeeded in the course of the next few centuries by somewhat damper or cooler conditions of the fluvial period, and in turn there has been a change to our modern drier period.

The Caspian Sea and the Aral Sea are salt lakes, which owe their saltness to their having been originally part of the ocean, from which they were separated, in the opinion of Russian geologists, by underground movements or warping of the earth's crust at a comparatively recent geological period. These movements, according to Helmersen,[1] are still in progress, and this has been given as one reason for the desiccation of the Central Asiatic area. The Tertiary deposits of the north of India show that elevation must have gone on in Central Asia continuously during the Tertiary period, and at the present time the same process is being steadily continued. It is interesting to note in this connection that the western portion of North America has similarly been undergoing a steady elevation, and at the same time a continued desiccation has been in progress.

The molluscs living in the waters of the Caspian Sea are very much like those living in the Black Sea, and banks of similar shells may be traced between the two seas. This and other evidence, together with the fact that many salt lakes and marshes are found in the district, indicate that the Caspian Sea was formerly connected with the Black Sea, and that a great firth running up between Europe and Asia stretched completely across what are now the steppes and plains of the tundras, till it merged into the Arctic Sea.

Caspian Sea, the largest inland body of water in the world, is 180,000 square miles in extent, and has a maximum depth of about 3200 feet, which makes it rank as the second deepest lake in the world (a sounding of 5413 feet has been taken in Lake Baikal). Its basin is naturally divided into three portions, of which the northern is the shallowest (maximum depth 120 feet), and is being gradually silted up by the deposits of the Volga, the Ural, and the Terek. A depression, half of which has a depth of more than 300 feet and reaches a maximum depth of 2526 feet, occupies the middle portion of the sea, and is separated from the southern and deepest portion of the Caspian by a submarine ridge, a continuation of the main Caucasus range. The Caspian receives the drainage of the

[1] Cited by Geikie, *Text-book of Geology*, ed. 2, p. 383, London, 1885.

whole south-east of Russia in Europe by such important rivers as the Volga and the Ural, but it has no outlet. So large is the mass of fresh water poured into it, that the greater part of the lake-water is less salt than that of the ocean, but the results of evaporation are seen in its being relatively more sulphatic. The amount of water supplied to the Caspian balances that lost by evaporation; nevertheless, along the shore in summer much evaporation goes on in lagoons, and the Gulf of Karaboghaz on the east shore may be regarded as a huge evaporating basin, 7500 square miles in area. It is no more than 50 feet in depth, and is connected with the main basin of the Caspian by a channel about 150 yards wide and 5 feet deep. It has been proposed to dam the strait in order to raise the level of the Caspian and to increase its salinity. The Gulf is situated in a warm region, and loses so much water by evaporation that its level is always lower than that of the Caspian. Consequently a current from the latter is continually flowing in, while there is no compensating under-current outwards. The salinity of the water is about 16 per cent., and Baer[1] estimated that 350,000 tons of salt were carried in daily; fish which enter the Karaboghaz from the Caspian are killed and naturally salted, and, it is said, supply food to the wandering tribes along its shores, who dig them out of the precipitated salt. The bottom of the Gulf is flat, and is covered in the central part over an area of about 1300 square miles by a bed of sodium sulphate (Glauber's salt), while in other parts calcium sulphate (gypsum) and mud are found.

It appears from the researches of Filippoff that during the years 1851–88 the level of the Caspian thrice stood at a maximum, the total range of the oscillations being 3½ feet. Besides these changes, there are also the seasonal ones (lowest level in January, highest in summer). Observations were made in 1904 by means of the Ekman apparatus on the currents in the Caspian, and showed that in the northern part there is a surface current flowing along the west coast towards the south; in the central part the current takes the same direction; sweeping round the southern shore, the current returns to the north along the eastern coast, almost to the peninsula of Manguichlague, where it deviates to the west to join that on the Caucasian coast.

Life, with the exception of bacteria, is absent in the deepest parts of the Caspian Sea. An oligochæte worm was got at a depth of about 1300 feet, but below that is an abyssal area totally destitute of life. This is due, not as in the case of the Black Sea to the presence of hydrogen sulphide, but to the scarcity of oxygen in the deep layers arresting the development of life. About 64 per cent. of the fauna

[1] Cited by Geikie, *op. cit.*, p. 383.

of the Caspian Sea, according to Knipovitsch,[1] are found nowhere else in the world. In its general character the fauna recalls that of a fresh-water lake rather than that of a true sea. Fresh-water fish, crustacea, and many plankton organisms met with in lakes and rivers are found; but there are also many typical marine organisms, which are not new arrivals but old inhabitants.[2] G. O. Sars believes that the Caspian may be considered as a centre of creation for plankton crustacea, and thinks that this evolution is still going on.[3] Seals and sturgeons are among the vertebrates represented; they are relics of the time when the Caspian Sea was united with the Black Sea, and probably also with the Sea of Aral, to form an immense sea, which had obtained its fauna from the ocean at a still more ancient time. The character of the fauna of the Caspian Sea changed in accordance with the lesser degree of salinity and the almost complete isolation of the basin. It became more and more peculiar, although 24·5 per cent. of the species are still met with in the Black Sea.[4] What is especially interesting is that the species common to the two seas are just those species which characterise the fauna of the shallow waters of the Black Sea; but as the water of the Caspian is comparatively fresh, and is not exposed to the invasion of foreign species from the Mediterranean, these forms are not limited to the estuaries of rivers, as in the Black Sea, but are found everywhere in the upper waters. The fauna of the Caspian Sea may be regarded as an ancient fauna relatively only slightly modified since remote times, the conditions of existence in the basin remaining nearly uniform since prehistoric epochs. The northern portion of the Caspian, which experiences severe frosts and is too shallow to store up large amounts of heat in the summer, freezes for three or four months along the shores, but in the middle portion ice appears only when it is brought down by northerly winds.

Lake Elton (or Yelton) is situated in the northern part of the Caspian depression, between the Volga and the Ural, a steppe region, studded with salt lakes, and so largely encrusted with salt that the rivers emptying themselves into these lakes are in some cases strongly saline. It is fed by the river Charysacha, which has 5 per cent. of saline constituents in its waters—that is, nearly a half more than the waters of the ocean—and is estimated to contribute nearly 22,000 tons of salt every year to the lake. From Lake Elton and the

[1] See Schokalsky and Schmidt, *Aperçu sur les Explorations scientifiques des Mers et des Eaux douces de l'Empire russe*, Section scientifique, Expos. Maritime Internat., Bordeaux, 1907, p. 34.

[2] See p. 358.

[3] "On the Polyphemidæ of the Caspian Sea," *Ann. Mus. Zool. St. Pétersb.*, t. vii. p. 31, 1902.

[4] See Schokalsky and Schmidt, *op. cit.*, p. 35.

lake or marsh of Baskunchatski, nearer the Volga, thousands of tons of salt are annually obtained.

Sea of Aral, once united to the Caspian Sea, but now lying about 246 feet above it, fills another of the hollows in the vast depression between the European and Asiatic high grounds. It is a lake of brackish water lying about 160 feet above the level of the sea, and 265 miles long, 145 miles broad, and with an area of about 24,400 square miles; the maximum depth is 222 feet, the mean depth 52 feet, while the volume of water is estimated at 36,744,000 million cubic feet. On the south the Amudaria (Oxus) carries into it the drainage from the northern slopes of the Hindu Kush Mountains, and on the east the Syrdaria (Jaxartes) brings down supplies of water and mud from the Thian Shan Mountains, the two rivers together delivering on the average about 52,980 cubic feet per second. Most of the water is derived from the melting of mountain snows, the months of maximum flow being June, July, and August.

Berg's expedition[1] of 1899–1902 supplied details, drawn from a consideration of the various measurements that have been made since the first survey of the lake by Admiral Butakoff in 1848, as to the changes in its level, and he made investigations on the temperature of the waters and on the existing life.

In 1848 the level of the water was relatively high, but during the years 1848–1880 it was undoubtedly sinking. Thus Glukhowskoy showed that the level fell 71 centimetres ($2\frac{1}{4}$ feet) between 1874 and 1880. From 1880 to 1899 no measurements were recorded, but in the latter year Berg found a rise of level in full progress, the water being higher than had ever previously been recorded; and the islands shown on Butakoff's map—which had become peninsulas in 1880—were submerged. Working from Tillo's bench-mark of 1874 at Karatamak, Berg found that the level in 1901 was 1·21 metres (4 feet) above that of 1874; in 1903, 2·75 metres (9 feet); and in 1908, 3 metres ($9\frac{3}{4}$ feet). The lake being mostly shallow, this rise corresponds to a very considerable increase in area; the increment in volume of water between 1880 and 1908 is estimated at 20 per cent. Berg gives the mean salinity of the water as 10·75 per mille (1·075 per cent.). Compared with analyses made between 1870 and 1880, which yielded an average of over 12 per mille (1·2 per cent.), this shows a marked freshening, due to the increase in the volume of water. Professor Woeikoff showed in 1901[2] that the changes in level are very well explained by the variations in precipitation, as indicated by pluviometric observations made at Barnaul, in West Siberia, since 1838. The annual amount of rainfall diminished from 1838 till 1868, then

[1] See Schokalsky and Schmidt, *op. cit.*, p. 36; *Geogr. Journ.*, vol. xix. p. 503, 1902.
[2] *Petermann's Mitt.*, Bd. xlvii. p. 199, 1901.

increased rapidly till 1895, and it has remained high with small variations since that year, the highest five-year average (to the end of 1906) being 1902–1906.

In general, the thermal stratification of the deep layers is similar to that in fresh-water lakes. Owing to its small depth (less than 3 per cent. of the lake-floor is covered by more than 100 feet of water), the surface temperature of Lake Aral varies considerably with the seasons, and in summer is much higher than that of the bottom. In winter the conditions are reversed, and consequently twice each year, in spring and autumn, the whole mass of water must be uniform in temperature.

The fauna of the Aral Sea is but slightly affected by the degree of salinity of the water; the same organisms can live in the open water, with a specific gravity of 1·0110, and in the bays, where the water is quite fresh. The fauna is related to that of the Caspian, but is characterised by a great poverty of species, on account of the difficulty of sustaining life in a comparatively salt shallow basin subject to great changes in temperature. The fish all belong to fresh-water species, and so do almost all the plankton organisms.

Lake Balkash, in Akmolinsk, Western Siberia, lies 780 feet above sea-level, and is merely a relict of a former much more extensive sheet of water, of which Sassyk-kul and Ala-kul are also remaining parts. It is 340 miles in length, 50 miles in maximum breadth, with an area of about 7000 square miles, but it is only about 33 feet deep,[1] and has a flat bottom. It was examined in 1903 by a Russian expedition under Berg,[1] and the temperature at the surface was found to be 76°·5 Fahr. (24°·7 C.) in July, while the bottom temperature varied very little. From the biological point of view it is as barren as the surrounding territories; there are only four kinds of fish, and no benthonic molluscs or other invertebrates were found. The plankton of the lake is abundant, and similar to that of ponds. One can only conclude that the lake is very young, and has not had time to people itself. The waters of Lake Balkash are quite fresh and fit for drinking, though the lake has no visible outlet, and lies in the middle of a steppe, where the evaporation is very great in summer, and the precipitation very insignificant; whereas Issik-kul, far more favourably situated, contains water that is much too salt to drink Berg accounts for this by supposing the lake to have been entirely dried up, the bed covered with sand, and then filled again. The lake has been rising in level since 1890.

Ala-kul (called also Kurghi-Nor or Alakt-Ugul-Nor), a lake of Russian Central Asia, in the province of Semirietchenisk, is 40 miles

[1] See Schokalsky and Schmidt, *op. cit.*, p. 53; the maximum depth is given in *Encycl. Brit.*, 10th ed. as 135 feet.

long and 17 miles broad, and lies 837 feet above sea-level. A smaller lake to the west, separated from the larger by a marsh, is also known as Ala-kul.

Issik-kul lies to the south of Lake Balkash, at an altitude of 5165 feet, and is 100 miles long by 30 or 40 miles wide, covering an area of about 2300 square miles. In the deepest portion of the lake, 33 miles from the southern shore, its depth is 1400 feet; in the middle portion a uniform depth of 840 feet prevails. The River Chu, after having approached very near the lake and discharged some of its waters into it by the short river Kutamaldi, suddenly turns northward and pierces a lofty mountain range. Davis[1] is of opinion that the low salinity of the lake waters is an indication that the Chu served once both as an inlet and an outlet to the lake.

Kyzyl-lak, in Akmolinsk, is 10 miles long by 8 miles broad, and is very salt. Ignatof,[2] who examined the salt lakes of Akmolinsk in 1898, found that the temperature varied from 70° to 84° Fahr. (21°·1 to 28°·9 C.), and at the bottom it was nearly 12° higher than at the surface. According to the natives of the region, the Kirghiz, it never freezes in winter. The colour of the water appears bright red, owing, Ignatof believes, to the large number of crustacea it contains.

In the neighbourhood are several fresh-water lakes, some of them several miles in diameter. How they came to be fresh is a mystery, unless, as Ignatof suggests, the shore-reeds have extracted all the salt from the water; but the explanation given by Berg for Lake Balkash seems more applicable.

Lake Selety-denghis is 40 miles long by 16½ broad, and is slightly salt. The temperature conditions are similar to those of Kyzyl-lak. The bottom is covered with decaying organic remains, and sulphuretted hydrogen is given off. The fauna consists of crustacea.

Lake Teke is 73 miles long by 10 broad, and is saturated with salt, and yet it contains several species of crustacea; no signs of drying up are perceptible as in the case of the other lakes, especially Kyzyl-lak.

Lob-Nor (or Lop-Nor), a lake of Central Asia, in the Gobi Desert, Gobi Desert.
between the ranges of Altyn-Tagh on the south and of Kurruk-Tagh on the north, lies at an altitude of about 2200 feet above sea-level, and is fed by the River Tarim, which has its source in the Thian Shan Mountains. A chain of numberless lakes accompanies the right bank of the Tarim throughout its course, lying in depressions in the sand, called by the natives "bajir." The prevailing winds blow from the east, and heap up the sand in ridges like gigantic waves, or pile it up in

[1] *Bull. Amer. Geogr. Soc.*, vol. xxxvi. p. 225, 1904.
[2] *Globus*, Bd. lxxv. p. 66, 1898.

vast accumulations of dunes, 300 to 400 feet high. In addition, there is another system of sand-dunes at right angles to the first, running from east to west, built by winds blowing from north to south during the winter. The sand-dunes, therefore, form a network, in which are depressions with a clay bottom swept free from sand. By the autumn the lakes are half empty.[1] Previous to 1876 Lob Nor was placed in nearly all the maps at a position which agreed with the accounts of ancient Chinese geographers. In that year the Russian, Prejevalsky,[2] discovered two closely connected lake-basins, Kara Buran and Kara Koshun, whose waters were fresh, fully one degree farther south and considerably to the east of the site of the old Lob-Nor. These lake-basins he nevertheless regarded as being identical with the Lob-Nor of the Chinese. This identification was disputed by Baron von Richthofen[3] on the ground that the Lob-Nor, the salt lake of the Chinese geographers and the terminal lake of a water-system, could not be filled with fresh water, and that this lake must be a modern formation. In 1895 Sven Hedin[4] ascertained that the River Tarim empties part of its waters into another lake, or rather a string of lakes (Avullu-köll, Kara-köll, Tayek-köll, and Arka-köll), situated in the latitude given to the Chinese Lob-Nor, and thus so far justified the views of Richthofen and confirmed the Chinese accounts. At the same time he advanced reasons for believing that Prejevalsky's lake-basins, the southern Lob-Nor, are of quite recent origin—indeed, he fixed upon the year 1720 as the date of their formation. Besides this, he argued that there exists a close inter-relation between the northern Lob-Nor lakes and the southern Lob-Nor lakes, so that as the water in the one group increases it decreases to the same proportion and volume in the other. He also considered that the five lakes of northern Lob-Nor are slowly moving westwards under the incessant impetus of wind and sand-storm (*buran*). These conclusions were afterwards controverted by the Russian geographer Kozloff, who visited the Lob-Nor region in 1893–94, before Sven Hedin. In 1900 Hedin, following up the course of the Tarim, discovered at the foot of Kurruk-Tagh the basin of a desiccated salt lake, which he holds to be the true Lob-Nor of the Chinese geographers ; and at the same time he found that the Kara-Koshun or Lob-Nor of Prejevalsky had extended towards the north, but shrunk towards the south. Thus the old Lob-Nor no longer exists, but in place of it are a number of much smaller lakes of newer formation. It is interesting to note that Dr Stein, in his paper

[1] Sven Hedin, *Central Asia and Tibet*, vol. i. p. 419, London, 1903.

[2] *Verh. Ges. Erdk. Berlin*, Bd. v. p. 121, 1878.

[3] *From Kulja across the Tian Shan to Lob-Nor*, pp. 98–145, London, 1879.

[4] *Through Asia*, vol. i. pp. 15 *et seq.*, vol. ii. pp. 864 *et seq.*, London, 1898.

"On Explorations in Central Asia, 1906–1908," in the *Geographical Journal* (vol. xxxiv. p. 26, 1909), says that at the time of his visit the new lakes found by Sven Hedin in the Lob Desert had almost disappeared. Sven Hedin, in the discussion on the same paper (p. 270), observes that whether this denotes that the lakes are in a period of shifting, or that in general the volume of water carried down by the Tarim has been diminished in recent years, can only be determined by comparison of the maps and measurements of the river.

From all this it may be fairly inferred that, owing to the uniform level of the region, the sluggish flow of the Tarim, its tending to divide and reunite, conjoined with the violence of the winds (mostly from the east and north-east) and the rapid and dense growth of the reed-beds in the shallow marshes, the drainage waters of the Tarim basin gather in greater volume now in one depression and now in another. This view derives support from the extreme shallowness of the lakes in both Sven Hedin's northern Lob-Nor and Prejevalsky's southern Lob-Nor.

Ellsworth Huntington sums up the history of Lob Nor thus [1]:—"We have first a comparatively large lake, said to measure 75 miles each way, in spite of the fact that the populous towns of Lulan and of more remote regions diverted much more water than now. Next, during the early centuries of the Christian era, there is a decrease in the recorded size of the lake, even though the towns of Lulan were being abandoned and their water was being set free to reinforce the lake. Then, in the Middle Ages, there was an expansion of the lake, which cannot have been due to diminished use of the rivers for irrigation, for the population of the Lop-Nor basin at that time was greater than now, though not equal to that of the flourishing Buddhist times, a thousand or more years earlier. Finally, during the last few hundred years there has been a decrease both in the size of the lake and in the population about it." This theory, Huntington says, seems to fit the facts, and all the facts are explicable on the theory of a secular change of climate from moister to drier conditions, with a rapid intensification in the early part of the Christian era, and a slight reversal in the Middle Ages. Hedin,[2] on the other hand, who utterly scouts the idea of any change of climate during historic times, recognises that during certain periods Lob-Nor has been distinctly larger than it is, even during times of unusually high water, at the present day. He explains this on the assumption that during these periods the number of marginal lakes and swamps on the Tarim River was less than now. The objection offered to this is that, when a river has reached the mature stage of the Tarim, the average

[1] *Bull. Amer. Geogr. Soc.*, vol. xxxix. p. 146, 1907.

[2] Cited by Huntington, *op. cit.*, p. 142.

quantity of water diverted to marginal lakes is nearly constant throughout any period of long duration, though it may vary from year to year. A *permanent* change in the size of the lake could not result from this. Moreover, in one case at least, the river, the marginal lakes, and the terminal lake all expanded, and later contracted, in unison.

Bojante-kul, to the north of Lob-Nor, about 130 feet below sea-level, lies in the Turfan or Lukchun depression, a strip of land about 200 miles long by 50 miles broad. It is probably the remnant of a much larger lake which received the waters from the glaciers of the Eastern Thian-Shan Mountains during a past epoch.

Pangong (or Pankgong) **Lake** is the largest and the lowest of a series of five lakes all lying at nearly the same altitude, about 14,000 feet above sea-level, and separated only by deltas two or three miles wide, like that of Interlaken in Switzerland. The five lakes are really one, which has been divided into parts by the deposits of tributary streams, and they may be regarded as occupying a single basin with a length of 105 miles, a maximum breadth of 4 miles, and an average breadth of only 2 miles. Drew [1] and others ascribe the formation of the lakes to the damming back of the original drainage by fan-deltas, and hold that its waters formerly drained to the Shyok, a tributary of the Indus. On the other hand, Ellsworth Huntington,[2] who visited the region in May 1905, believes that there must be a rock lip which blocks the outlet, and that the basin behind the lip has been eroded by ice, resembling in this way the fiords of Norway and the valley lakes of Switzerland. He is of opinion that the streams that formed the fan-deltas were quite incapable of obstructing the main stream of the valley, which must have had a considerable volume. There is abundant evidence of glacial action in the vicinity of the lake, and lacustrine deposits and shore-lines indicate fluctuations in lake-level in response to changes in climatic conditions. During Huntington's visit the ice broke up under the influence of a very strong wind, and part of it was piled up on shore in a ridge 8 or 10 feet high. The sandy beach had been pushed up by the ice, and flat stones moved so as to add to the mounds of loose earth and stones and furrows of more cohesive shore-deposits which lie parallel to the water's edge and form a rampart [3] from 6 inches to a foot in height round the lake. By

[1] Drew, *The Jummoo and Kashmir Territories*, p. 317, London, 1875.

[2] See *Journ. of Geology*, vol. xiv. p. 599, 1906.

[3] G. K. Gilbert, in a paper in the *Bulletin of the Sierra Club* (Jan. 1908), discusses the phenomenon of lake ramparts, which is one of considerable interest in connection with ice problems. On the shores of many lakes in the Sierra regions, as also on the shores of Canadian lakes, and of those in some other parts of North America and in parts of Northern Europe, rows of boulders of various sizes up to a diameter of several feet occur, sometimes forming a low

testing the degree of saltness in the water after, as compared with before, the disappearance of the ice, he came to the conclusion that a large part of the ice had been melted by the salter warmer water which had displaced the surface film of fresh cold water, on account of currents set up by the wind. Henderson says[1] the lake is too salt for fish to live in it (salinity[2] 1·3 per cent., 0·6 per cent. being sodium chloride, and 0·4 per cent. sodium sulphate), and the only animal life he could find was a small Crustacean, probably a *Gammarus*.

Koko-Nor (or Kuku-Nor, Blue Lake), lies 10,500 feet above sea-level, not far from the sources of the Hoang-Ho and Yangtse, and has a circumference of about 200 miles.

Tengri-Nor (called Nam-tso, or "sky lake"), in the vicinity of Lhassa, lies 15,190 feet above sea-level. It is the most easterly link in a vast lacustrine chain which stretches for hundreds of miles north-west and south-east across the plateau of Tibet, and which includes the large lakes Kyaring, Chargat, Zilling-tso (15,128 feet above sea-level), Ngangtse-tso (15,417 feet above sea-level, max. depth 27 feet).

Dangra-yum-tso, Teri-nam-tso, "the heavenly lake" (15,367 feet above sea-level); **Lapchung-tso** (17,039 feet above sea-level); **Lake Lighten** (16,709 feet above sea-level; depth over 213 feet; temperature of surface water at 11 a.m. in September, 43° Fahr.); **Yeshil-kul** (16,207 feet above sea-level; maximum depth, 53 feet; temperature of surface water at 1 p.m. in September, 49° Fahr.).

South of Tengri-Nor, and separated from it by the River San-po, is the ring-shaped Lake Palti, or Tomdok, divided into two basins by a peninsula.

Manasarowar ("the Holy Lake," Tso-mavang) and **Rakas-tal** (Langak-tso) lie to the south-east of Pangong Lake, between 30° and 31° N. latitude. Very plainly marked shore lines are to be seen round

rampart, at other times a mere line, but always close to the water's edge. The boulders in every way, except in their regularity of arrangement, resemble the glacial erratics which are scattered over the adjacent land-surface, and they only occur in regions where the winter sheet of ice reaches a considerable thickness, and where winter temperatures are extreme. The ice expands with a rise and contracts with a fall of temperature, and while the under surface of a thick layer of ice is kept more or less constantly at a temperature of 32° Fahr., owing to its contact with the water beneath, the upper layer contracts and expands with temperature variations in the air. The result is the formation of extensive cracks during severe frost, followed by expansion under a sudden rise of temperature, and the consequent buckling of the ice-sheet, which is pushed up over the shore at its margins. As it rises along a gently shelving shore it carries with it whatever solid bodies occur in the shallow water—hence the rampart formation.

[1] *Geogr. Journ.*, vol. xv. p. 430, 1900.

[2] Frankland's analysis in Henderson and Hume, *Lahore to Yarkand*, p. 370, London.

both lakes, indicating former higher levels, and an old river bed leading off from the north-east corner of Rakas-tal marks where formerly the waters issued from that lake to join the Sutlej River. Ryder believes that now both Manasarowar and Rakas-tal are entirely disconnected from the river at all times of the year.[1] Sven Hedin,[2] on the other hand, regards the two lakes as belonging to the drainage area of the Sutlej, and the Tage-tsangpo, the largest stream discharging into Manasarowar, as the head water of that river. He followed the old bed of the Sutlej River westwards from Rakas-tal, and came first to a large pool of fresh water, then to a series of fresh-water swamps connected by channels, and at length to a brook flowing south-westwards. The brook discharges into a large fresh-water pool with no visible outlet, but further on springs well up on the bottom of the old bed, and he is convinced that the water filtrates underground to these from Langak-tso.

A channel about five miles long connects the two lakes, and when the precipitation is abundant water flows from Lake Manasarowar to Rakas-tal. At all times, according to Sven Hedin,[3] there is a connection by underground passages. Rakas-tal freezes in the beginning of December, half a month sooner than Lake Manasarowar; but it also breaks up half a month before that lake. Both lakes have ice 3 feet thick, but in the case of the former the freezing proceeds slowly and in patches, whereas the latter freezes over in an hour.

In winter the surface of Lake Manasarowar falls 20 inches beneath the ice, which is consequently cracked and fissured, and dips from the shore; whereas Rakas-tal sinks only one or two thirds of an inch: this is taken as showing that Rakas-tal is constantly receiving water from the eastern lake.

Manasarowar, 15,098 feet above sea-level, has an outline somewhat like that of a skull seen from the front. It measures about 12 miles from east to west by 15 from north to south, and has an area of about 110 square miles. Sven Hedin made in all 138 soundings on the lake, and found the greatest depth to be 268 feet. He also measured the amount of water discharged by each of the rivers flowing into Manasarowar, and calculated the total volume flowing into the lake as 1095 cubic feet per second, but considers that probably a volume of water greater than this surface supply is contributed by subterranean springs, fed by the melted waters of the glaciers on the mountains surrounding the lake. The temperature of one of these

[1] C. H. D. Ryder, "Exploration and Survey with the Tibet Frontier Commission," *Geogr. Journ.*, vol. xxvi. p. 388, 1905.

[2] *Trans-Himalaya: Discoveries and Adventures in Tibet*, London, 1909, p. 182.

[3] *Op. cit.*, p. 168.

springs where it welled up to the surface was about 38° Fahr., and Sven Hedin is of the opinion that the springs assist in keeping the waters of the lake cool.

Rakas-tal, 15,056 feet above sea-level, is very irregular in outline: it is 16 miles in length, and the width varies from 4 miles in the north to about 13 miles in the south. The lake is very stormy, and Sven Hedin was able to take only a few soundings. He found the greatest depth in the northern part to be 54 feet, while in the south, in the middle of the sound between the island La-che-to and the mainland, the depth was 113 feet.

Lake Hámun.—The Seistan is described by Sir H. M. M'Mahon [1] as a large depression, some 7000 square miles in area and without any outlet to the sea, which receives all the drainage of a vast tract of country, extending to over 125,000 square miles, girt on all sides by high mountain ranges. It lies half in Afghanistan and half in Persia, and is about midway between the Russian-Turkestan border and the Persian Gulf. The Hámun, or lake area, into which the various Seistan rivers discharge their surplus waters, lies in the north and north-west parts of the depression. In spring and early summer the Khash, Tarah Rud, and Harut Rud bring large volumes of water from the north, but during a portion of the year their higher waters are taken off for irrigation. The Helmund, the principal river of Seistan, 600 miles in length, rises near Cabul, drains a large portion of Afghanistan, and divides into three branches after arriving in Seistan. In the flood season the Hámun becomes a vast sea, more than 100 miles in length, and varying from 5 to 15 miles in breadth. Every few years, when the water reaches a certain height, it escapes through the Shelag channel into another large and still deeper lake-depression called the Gaud-i-Zirreh. When the Hámun water, which is singularly free from salt, overflows through the Shelag, the water in that channel becomes drinkable; but at other times the water found throughout its course in large stagnant pools is nearly pure brine, with solid salt crystals round the margins. Evaporation is very rapid in the region of the Seistan, owing to the heat and the strong winds, and as the water of the Gaud-i-Zirreh dries up, a thick deposit of salt is left behind. According to T. R. J. Ward, Irrigation Officer of the 1903 Mission for the survey and exploration of Seistan, 10 feet of water is removed by evaporation alone in a year.

Seistan depression.

The Lake of Bákhtegán (also known as the Lake of Niriz) is situated in Fars, a province in the south-west of Persia, bordering on the Persian Gulf, and is fed by the Kur and its affluents.

[1] *Geogr. Journ.*, vol. xxviii. p. 209, 1906.

Persian plateau.

Lake Urmi (or Urumia) is situated on the plateau of Urmi, the water-parting between the rivers flowing into the Caspian Sea and those flowing into the Persian Gulf, about 4100 feet above sea-level, and covers an area of 1750 square miles. Lord Curzon [1] has estimated its length at about 85 miles, its breadth at 20 or 30 miles, and its circumference at nearly 300 miles. Its greatest depth probably does not exceed 40 feet, and its average depth appears to be not more than 15 feet, but it varies in size with the season of the year, and is also subject to fluctuations occurring in longer and less regular cycles. Much of the rainfall of the region is lost by evaporation from the plains surrounding the lake, and the mountain torrents are redistributed among irrigation canals.

In 1898 Günther made a special study of the lake,[2] including observations on the temperature, specific gravity, refractive index, etc. The temperature of the waters varied from 78° to 82° Fahr. (25°·5 to 27°·7 C.) in August, according to the direction of the wind. The average temperature at the surface was about 80° Fahr., and at the bottom, in 25 feet of water, some 2° lower. Owing to the great seasonal variation in the level of the water, the composition and specific gravity undergo considerable alteration during the change from the dry season level to that of the wet season. The salinity of a sample of water obtained on 16th September 1898, was 14·85 per cent. (about four times as salt as the open ocean). The specific gravity of the water, measured on the spot with an ordinary hydrometer, was 1·11 at the surface and also at the bottom, so that, remote from the mouths of fresh-water streams, the lake-water was of fairly uniform density. This may have been due to the thorough mixing of the waters by the strong south-easterly winds which prevailed at the time the experiments were made.

The water of the lake is far too salt to permit of the existence of any of the fresh-water fish from the inflowing rivers that may happen to swim out too far, so that the lake forms an efficient barrier to the migration of fish from one river to another. At present the organisms inhabiting the lake are a species of *Artemia* (a crustacean known from other brine lakes in Europe and North America), the larva of a species of dipterous insect, most probably allied to *Ephydra*, and green vegetable masses, which are described by George Murray [3] as composed of bacterial zoogloeæ of micrococci invested by a number of small diatoms. Several fresh-water sponges appear at the foot of a conical hill that rises abruptly from the margin of the lake.

[1] Lord Curzon of Kedleston, *Persia*, p. 532, London, 1892.

[2] See *Proc. Roy. Soc.*, vol. lxv. p. 312, 1899.

[3] *Journ. Linn. Soc. Lond.*, Zool., vol. xxvii. p. 356, 1899.

Lake Van lies in Eastern Anatolia, in Asiatic Turkey, on one of the elevated plains separated by mountain ranges, in the volcanic district of Van, at a height of about 5200 feet above sea-level, and has an area of 2000 square miles. It is 80 miles long and 30 miles broad, and over 80 feet deep. The lake is said to be connected with the Euphrates through the little lake of Nazik, which lies on the watershed between Lake Van and the river, and sends emissaries to both—a rare phenomenon. Anatolia.

Lake of Gyoljuk, 12 miles long by 2 or 3 miles wide, lies 3 degrees west of Lake Van, at an elevation of 4000 feet among the Taurus Mountains, between the head-waters of the Euphrates and Tigris Rivers. Under present climatic conditions the lake is on the dividing line between a so-called "normal" fresh-water lake with a permanent outlet and a salt lake with no outlet. In years of large rainfall it overflows and forms one of the most remote sources of the Tigris, but in drier years the lake has no outflow during the long rainless summer. Its waters contain borax, but the amount is not so great as to render the water undrinkable. In former times, judging by the evidence furnished by historical accounts and local traditions, Lake Gyoljuk appears to have fluctuated in size in the same manner and at the same periods as the Caspian Sea, and Ellsworth Huntington[1] considers that this gives good ground for believing that Turkey has undergone changes in climatic conditions similar to those which have affected Central Asia.

The inland drainage areas of Arabia and Asia Minor (see fig. 64) cover an area of about 782,000 square miles.

Arabia may be roughly divided as to its surface extent into one third of coast ring and mountains—part barren, part either cultivated or capable of cultivation,—another third of central plateau also tolerably fertile, and a third of desert intervening between the first and second except in the region of Mecca. Surface streams are almost wanting even in the more fertile districts, because of the excessive evaporation and light and porous quality of the soil. Water is obtained for the most part from wells, sometimes 20 or 30 feet deep; but though in the Kaseem valley in the interior it abounds at a depth of only a few feet below the ground, and occasionally collects on the surface in perennial pools, none of these are large enough to deserve the name of lakes. Arabia.

In the central and southern portions of the plateau of Asia Minor the streams either flow into salt lakes, where their waters pass off by evaporation, or into fresh-water lakes which have no visible outlet. In the latter cases the waters find their way by subterranean channels beneath the cretaceous limestones of Mount Taurus, and reappear as Western Asia Minor.

[1] *The Pulse of Asia*, p. 356, London, 1907.

Fig. 64.—Inland drainage areas of Arabia, Asia Minor, and the so-called Great Rift Valley.

[The inland drainage areas are stippled.]

the sources of the rivers flowing to the coast. Thus the Egerdir Gol and the Kereli Gol supply the rivers flowing to the Pamphylian plain by subterranean channels.

Tuzlah Lake (or Tuz Gol).—The largest lake is called by Strabo Tatta, and by the Turks Tuzlah, or the Salt-Pan, an epithet well deserved from its extreme saltness, which exceeds even that of the Dead Sea. It lies at an elevation of 2525 feet, and is about 45 miles in length by 18 miles in breadth, but varies in extent with the season, sometimes covering an area of 700 square miles. Being very shallow, a considerable portion dries up in summer, and becomes covered with an incrustation of salt.

Egerdir Gol and **Kereli Gol**.—The two lakes, Egerdir Gol and Kereli Gol (so named from towns on their shores), situated between the ranges of the Sultan-dagh and the Taurus, are both about 30 miles in length. The former lies about 2800 feet above sea-level, and the latter about 800 feet higher. Both are perfectly fresh, and their waters clear and deep, though Egerdir Gol has no visible outlet, and Kereli Gol communicates only by a small stream with the Soghla Gol, the waters of which occasionally disappear entirely. The waters are, as already stated, carried off by subterranean channels.

Buldur Gol lies at an elevation of 2900 feet, and is about 17 miles in length by 4 miles in breadth.

Tchoruk Su Gol (or Lake of Chardak) is a smaller lake lying to the north-west of Buldur Gol. Its waters are extremely salt, and large quantities of salt are collected from it.

Palestine area.

The inland drainage area of Palestine, according to some writers, forms part of the so-called Great Rift Valley, running from the base of the Giaour Dagh, a range of mountains on the borders of Asia Minor and Syria (between lat. 37° and 38° N.), to the Red Sea, and extending far into the heart of Africa, which will be referred to more particularly when dealing with the African lakes. The Jordan rises west of Mount Hermon, 1050 feet above sea-level, and, after spreading out into Lake Huleh (Waters of Merom) and the Sea of Galilee (Lake of Tiberias), discharges its waters into the Dead Sea. From the small Lake Huleh, only 6 feet above the level of the Mediterranean, to the Dead Sea, which is salt and has no outlet, the course of the Jordan is below sea-level.

Lake of Tiberias (Sea of Galilee) lies 682 feet below sea-level, and is 12½ miles long and 7½ miles in greatest width. The waters are fresh and clear, and abound in fish. Barrois[1] affirms that the lake is nowhere deeper than 130 to 148 feet, according to the season, though very much greater depths were previously given by other writers (936 feet, Macgregor; 820 feet, Lortet). The surface

[1] See *Quarterly Statement*, *Palestine Exploration Fund*, 1894, p. 211.

temperature varies greatly: thus, on 2nd May it was $73\frac{1}{2}°$ Fahr. (23° C.) at 8.45 a.m., 79° Fahr. (26° C.) at 2.30 p.m., and 69° Fahr. (20°·5 C.) at 9 p.m., the fall being caused by a fresh north-westerly breeze. The temperature was 68° to 69° Fahr. (20° to 20°·5 C.) at a depth of 30 feet, and fell to 62° or 63° Fahr. (16°·7 or 17°·2 C.) at 50 feet. Between 65 and 130 feet the water had a uniform temperature of 59° Fahr. (15° C.). This is a much higher temperature than is observed in the Swiss lakes at the same depth, and is partly due to the lower latitude and lower altitude (682 feet *below* sea-level), and partly to the hot springs which pour their waters into the lake, besides others which probably rise from the bottom.

Dead Sea lies 1292 feet below sea-level. It is 46 miles long, and varies in breadth from 5 to 9 miles, the area being about 360 square miles. The greater part of what is known regarding the depths and shore-line of the Dead Sea was ascertained by the United States expedition sent out in 1847 under Lieutenant Lynch,[1] who found a maximum depth of 1278 feet in the northern portion.

The affluents of the Dead Sea carry to it every twenty-four hours from six to ten million tons of water, which must all be lost by evaporation, so that the water of the sea contains much dissolved matter (24 to 26 per cent., as compared with the 3 to 4 per cent. of ordinary sea-water), and its specific gravity is 1·13, while that of the Atlantic in lat. 25° N., long. 52° W., is 1·02. Mr W. Ackroyd[2] believes that the two causes usually assigned for the saltness of the water—viz. the accumulation of chlorides derived from the rocks of the Holy Land by solvent denudation, and the cutting off of an arm of the Red Sea by the rising of Palestine in past ages—are inadequate, and that a third cause, probably more important than either, is the atmospheric transportation of salt from the Mediterranean. The salt is brought from the sea by winds, finds its way into the rivers and thence into the Dead Sea, where the saline solution continually becomes salter by evaporation.

The surface of the Dead Sea is liable to frequent fluctuations in level, due to a succession of exceptionally dry or rainy seasons, to the greater or lesser activity of subaqueous springs, to landslips, to changes in the drainage, to the gradual silting up of the basin, and possibly to slight earth-movements which escape detection. The annual rise and fall is estimated at from 6 to 10 feet, but there seem to be also prolonged periods of high and low level. Lines of driftwood and marks on the rocks show the limits of rise which might occur under existing conditions, and a fall of 15 feet is quite possible during exceptional periods of dryness.

[1] See *Amer. Journ. Sci.*, vol. lvii. p. 324, 1849.

[2] See *Quarterly Statement, Palestine Exploration Fund*, January 1904, p. 64.

Hill,[1] writing in 1900, said that the surface of the Dead Sea had risen considerably, as the Rujn el Bahr, an island existing a few years before near the north end of the lake, had disappeared, and the Jordan had been invaded by the lake, and much of the land in the neighbourhood submerged; the beach on the east shown in the Exploration Fund map had also disappeared, water of considerable depth coming close up to the cliffs and rocks. He suggested that volcanic action might be raising the bed of the lake. The water does not appear to fall during the summer, so the rise cannot be due to the rainfall at any particular season; but it is possible that a wet cycle may have set in, and the rise may be due to the increased rainfall of late years.

On the other hand, according to a note in the *Deutsche Rundschau*, referred to in the February *Geographical Journal*[2] of 1900, the water of the Dead Sea had recently undergone a marked diminution in volume, mainly, it was said, owing to the increased diversion of the water of the Jordan for irrigation purposes. The bed of the lake was said to appear like a deposit of dry salt. Monthly measurements of the rise and fall of the lake taken for the Palestine Exploration Fund during an exceptionally dry year, October 1900 to October 1901, showed a rise of 1 foot 3 inches up to 30th March 1901, and then a fall of 1 foot 9 inches to October. Thus the level of the lake was lowered 6 inches in the year. Dr Masterman, who made observations of the fluctuation of the level of the Dead Sea from 1901 to 1906, reported[3] that 37·95 inches of rain had fallen between autumn 1905 and spring 1906, and the level had risen 34 inches. The figures given for the years 1901–1905 show that the extent of the rise is not always proportional to the rainfall. Putnam Cady[4] reports that at certain points along the shore on the east coast great quantities of oil flow from the rocks and spread over considerable portions of the sea. On the shore large pieces of pure sulphur and lumps of bitumen weighing several pounds were found. He also writes of a strong current setting towards the north along the east coast, and of disturbances of level due to differences of barometric pressure at different points on the lake.

Lynch[5] states that no animalcules or animal matter were detected in the water by a powerful microscope, although the surface of the sea one evening was a wide sheet of phosphorescent foam, a phenomenon

[1] *Quarterly Statement, Palestine Exploration Fund*, July 1900, p. 273.

[2] See vol. xv. p. 175, 1900.

[3] *Quarterly Statement, Palestine Exploration Fund*, July 1906.

[4] "The Historical and Physical Geography of the Dead Sea Region," *Bull. Amer. Geogr. Soc.*, vol. xxxvi. p. 585, 1904.

[5] *Op. cit.*, p. 324.

usually attributed to the light-emitting powers of minute organisms. On the other hand, it is stated[1] that the investigations of Ehrenberg and Lortet show the existence of "certain inferior organisms and microbes" in the Dead Sea.

NORTHERN AFRICA. The inland drainage area of Northern Africa (Sahara and Sudan) covers an area of about 3,450,000 square miles (see fig. 65).

The Sahara, the largest continuous desert on the earth's surface, stretches across the continent of Africa eastwards from the Atlantic for a considerable distance on both sides of the Tropic of Cancer, and forms part of the great arid belt extending across the Old World from north-eastern Asia to the borders of the Atlantic Ocean. To the north, in Morocco and Algeria, the limits of the region are defined by the Atlas range, but in other directions the boundaries are vague, and in the south the desert merges gradually and irregularly into the well-watered plains of the Sudan. The Sahara is a region of varied surface and irregular relief, ranging in altitude from 100 feet below sea-level to some 5000 or 6000 feet above it, and containing, besides sand-dunes and oases, rocky plateaus and ranges of hills.

Sahara. The lakes of the Sahara are termed Shotts or Sebkas; they are shallow, have no outlet, and are very salt, and in summer the heat of the sun often causes the water to evaporate, leaving behind a white sea of salt crystals. The streams flowing southward from the Atlas Mountains are diverted for irrigation purposes, so that the Shotts only receive their waters after the copious rains of winter and the melting of the snow in the mountains. Shott el Melrir, Shott el Gharsa, Shott el Jerid, and Shott el Fejej form a series of marshes or shallow lagoons extending from the south of Biskra (lat. 35° N., long. 5° E.) eastwards to the Gulf of Cabes, and occupy a depression below the level of the sea. At one time it was proposed by the French engineer, Colonel Roudaire, to flood this region. Shott el Melrir occupies the bottom of the depression, and in summer its surface is partly covered with a coating of salt crystals, while its floor is covered by black, viscous mud emitting an odour of garlic, due possibly to the presence of volatile sulphur compounds; veins of more solid ground form natural causeways. Shott el Jerid is the largest, and with its eastern extension, the Shott el Fejej, covers an area of several hundred square miles. It lies about 60 feet below the sea, with which it seems formerly to have communicated through a now nearly dry coast stream.

When on my way to Tuggurt in May 1900, I arrived on the cliff overlooking the Shott el Melrir late in the afternoon. The Shott was then a vast white expanse, which reminded me of the view of the Arctic Ocean from Flemish Cap at the north of Spitzbergen. Early

[1] Gautier, art. "Dead Sea" in *Encycl. Biblica*, vol. i. col. 1044, 1899.

the following morning the salt had all disappeared, having deliquesced during the night, and the Shott looked like an ordinary lake.

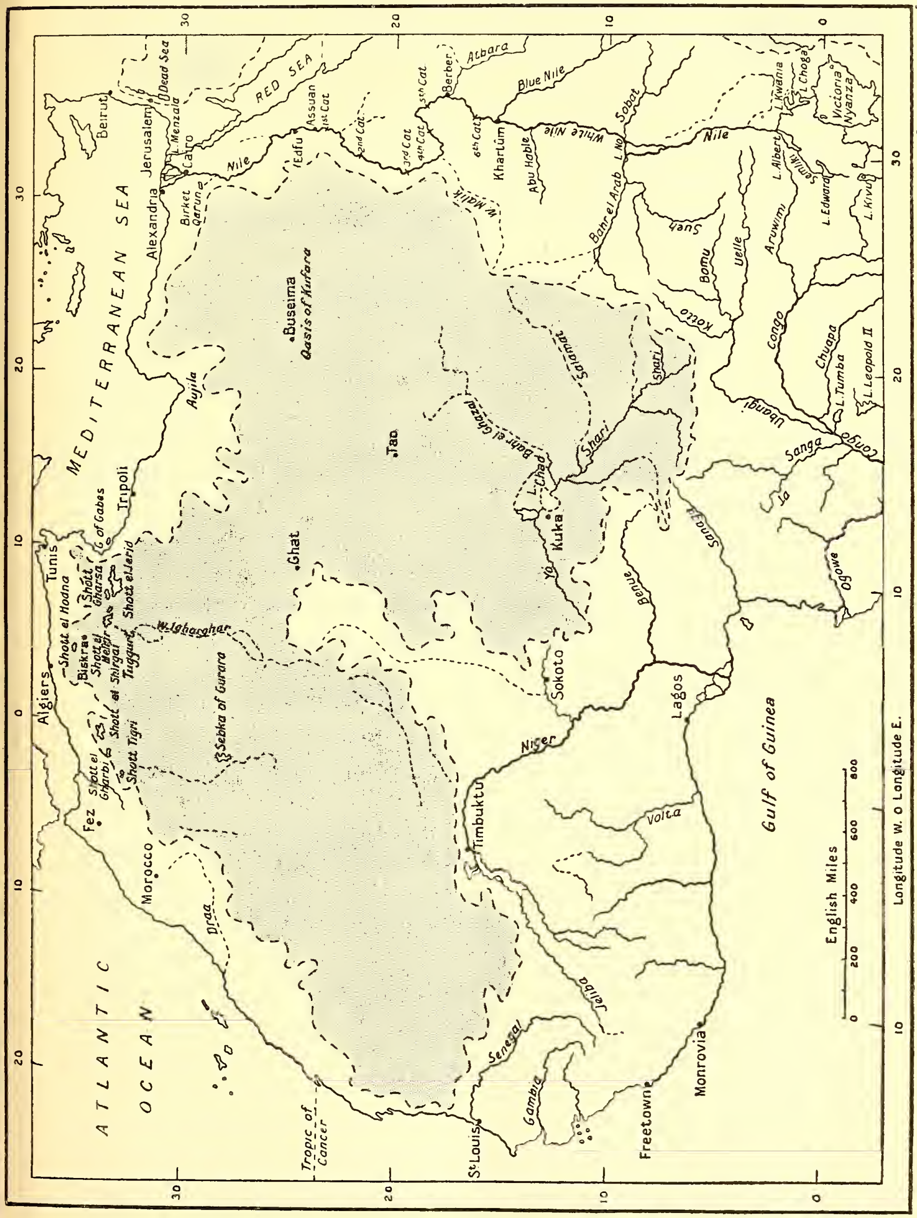

FIG. 65.—Inland drainage area of Northern Africa (Sahara and Sudan).
[The inland drainage areas are stippled.]

Shotts, or Sebkas, are found not only in the Sahara proper, but in the region of Algiers called the High Plateaus, as Shott el Tigri, Shott el Gharbi, Shott el Shergai, and Shott el Hodna.

Shott el Tigri is wholly in Morocco. Shott el Gharbi, or Western Shott, is on the Morocco frontier, and is followed by Shott el Shergai, or Eastern Shott, 140 miles long, at the foot of Mount Saida. Then come the Zahrez-Gharbi, the Zahrez Shergai, the Shott el Hodna, and, beyond Batna, towards the Tunis frontier, the Tarf and other lagoons of the Haracta depression.

The waters of many of the rivers that flow towards the Sahara either disappear in the permeable strata, or are buried by the drifting sand, and flow along the underlying clayey stratum. Owing to local causes, such as the cropping up of a bed of rock across its course, the buried water may come to the surface and form an oasis with an ordinary well, or it may be caused to rise by boring, thus forming an oasis with an artesian well. The many artesian wells sunk by the French in this region have brought fertility where there was formerly unproductive waste. In one part of the Sahara, the Souf, the water circulates close to the surface of the soil, concealed by a bed of sulphate of lime, and in planting date-groves the entire crust is removed, the palms being planted in the water-bearing sand below; this is termed an excavated oasis.

The Oued Igharghar is a long depression, having its origin in the land of the Tuaregs on the Ahaggar plateau, about the latitude of the Tropic of Cancer, and extending northwards over 750 miles to Shott el Merwan, the southern extension of Shott el Melrir. About 60 miles above Shott el Melrir it is joined by a similar depression, the Oued Miya, and after the junction is known as the Oued Rhir. Although in many parts almost effaced by drifting sands, its bed is still followed by the native caravans. Salt lakes are found at intervals throughout the whole extent of the Oued Rhir; and as the so-called Bahr Tahtani or "Lower River," which flows along an impermeable bed beneath the channel of the Oued, has been reached by boring, a never-failing supply of fresh water can be obtained through artesian wells. The towns of El Marier, Tamena, Tuggurt, etc., are situated on a continuous line of oases, many of which are artificially formed. The sinking of wells in this Oued led to the discovery of fishes, crabs, and fresh-water molluscs at considerable depths in the artesian well called Mezer, near Shott el Melrir.[1] The presence of these fishes and crabs seems to prove the existence of running water beneath.

In the zone of the Areg, or country of the sandhills, the moving sand arrests the course of the running water, and causes pools or marshes (Dhaya) to form, neither very large nor very deep. They are

[1] *Chromis Desfontainei*, *Chromis Zilii*, *Hemichromis Saharæ*, *Hemichromis Rollandi*, *Cyprinodon calaritanus*, *Telphusa fluviatilis* (see Paul Regnard, *La Vie dans les Eaux*, pp. 103–105, Paris, 1891); see also Tchihatchef, "The Deserts of Africa and Asia," *Rep. Brit. Assoc.*, 1882, p. 356.

little Shotts which present the same phenomena as the greater depressions in the Lower Sahara. The Arabs compare the moving sand to a net; it occupies a fairly extensive zone in both the Lower and the Upper Sahara, but does not cover one-third of the whole Algerian Sahara.

The Sebka of Gurara (lat. 29° N., long. 2° W.) is a saline depression, measuring about 60 miles in a N.N.E. to S.S.W. direction. It seems to be marked by more or less humidity throughout, the moisture being derived from the underground supply, fed by the drainage of the southern slopes of the Atlas, which here comes to the surface. In the course of the whole depression there are three main basins, known as the Shotts of Dahram, Shergi, and Gebli, though even in these there does not seem to be permanent water above the surface.

Lake Chad (or Tsad) occupies the centre of a vast area of inland drainage in the Sudan. It lies about 850 feet above sea-level, and varies in area from 7700 to about 20,000 square miles, according to the season. During the rainy season, when the lake is expanding, the water is fresh and limpid; it becomes slightly salt only at the period of low water, *i.e.* in May and June. Numerous lagoons scattered along the shores of the lake are really salt marshes, and, according to Captain Dubois,[1] play a rôle in the economy of the lake analogous to that of Karaboghaz in the Caspian Sea. When the lake expands these lagoons receive an enormous quantity of water, which, once communication is cut off by the receding of the lake in the dry season, concentrates and finally disappears by evaporation, leaving behind a deposit of salts. In this way every year Lake Chad partially clears itself of dissolved salts automatically, and the concentration of the waters by evaporation in the main lake during the dry season is arrested. The chief inflow to the lake is the River Shari, entering from the south-east, but it has no outflow, except when it overflows into the lagoons in the manner mentioned above. Sudan.

The lake, according to Destenave,[2] is constantly retreating towards the west, and so a continually increasing number of islands is forming in the east, which are becoming more and more populated by tribes formerly settled in Kanem, the arid district to the east of the lake.

A wide valley, called Bahr el-Ghazal, stretches towards the north-east from the south-east extremity of the lake. This valley, which is now waterless, served formerly as an outflow from the lake at times of high floods, the water leaving the lake gradually losing itself by evaporation in the more arid regions of the Sahara. The same name,

[1] See Destenave, "Exploration des îles du Tchad," *La Géographie*, t. vii. p. 425, 1903.

[2] *Loc. cit.*

Bahr el-Ghazal, is also given to a broad current which flows from the mouth of the Shari River to the eastern extremity of the lake, following the shore to the north-west side of the lake, where it gradually loses itself.

Lieutenant Boyd Alexander[1] explored Lake Chad in 1904, and found progress across it by boat to be extremely difficult, owing to the great belts of high reeds and the shallowness of the water. He describes the lake as being practically divided into two basins by about 25 miles of marsh and thick bush. The northern basin, which receives the waters of the River Yo, is the shallower, apparently not exceeding 4 feet in depth. The southern basin, into which the Shari flows, has a depth of about 12 feet in places, and the islands in it, which form a prominent feature, are fertile and thickly populated. The lake, which is generally shallow and swampy, opens out into a fine sheet of water round the mouth of the Shari.

The **Aujila Depression** is a remarkable zone of oases or depressions extending from the Wady Fareg, near the south-east angle of the Gulf of Sidra on the coast of Tripolis, eastwards to the Bahriyeh (Lesser) Oasis in Middle Egypt. This depression assumes somewhat the aspect of a long, winding, dry water-course, expanding at intervals into patches of perennial verdure and shallow saline basins, and was thought by some to have been of marine origin. Hence Rohlfs conceived the idea of again transforming this chain of oases into an inland gulf by admitting the Mediterranean waters through a cutting to the Wady Fareg and opening a waterway into the Libyan Desert. This project, analogous to Roudaire's scheme in respect of the Algerian Sahara, was subsequently abandoned when it was discovered that only one of the oases, Swah, with its eastern extension, was below sea-level.

Kufara Oases.—South of the Aujila depression in the heart of the Libyan Desert five oases, called the Kufara Oases, stretch for a distance of 200 miles north-west and south-east, with a total area of 7000 square miles. Although there are no surface streams, fresh water in abundance is easily obtained by tapping the underground water occurring at depths of from 3 to 10 feet on the margins of saline ponds and marshes.

Birket Qarun is a brackish lake in the lowest part of the Fayûm province of Egypt, a large circular depression in the Libyan Desert separated from the Nile valley by a strip of desert two to seven miles in width. A narrow watercourse, over 200 miles long, the Bahr Yusef, enters the lake through a gap in the Libyan Hills, connecting it with the Nile and forming a narrow neck of cultivation across the desert. The Birket Qarun is usually regarded as a remnant

[1] See *Geogr. Journ.*, vol. xxx. p. 119, 1907.

of the ancient Lake Moeris,[1] which covered at least a large part of the floor of the Fayûm depression. Lake Moeris was first described about 450 B.C. by Herodotus, who believed it to be an artificial basin constructed by one of the Pharaohs of the XIIth dynasty for the regulation of the water-supply of Lower Egypt. Its existence and position have been much discussed in modern times, but it is now believed that the Fayûm depression is a natural one, and King Amenemhat III., of the XIIth dynasty, is accredited with the formation of the lake about 2500 B.C., through the widening and deepening of the small canal already existing between the Nile and the depression, and placing it under artificial control. According to Major R. Hanbury Brown, Inspector-General of Irrigation for Upper Egypt, Lake Moeris covered the whole of the Fayûm up to the contour-line of 22·50 metres (74 feet) above mean sea-level,[2] and the greatest depth when the lake was at its full height would be about 70 metres (230 feet). At some time or other, either by a gradual or sudden process, the lake ceased to perform its offices of regulator and reservoir, and having once reached that stage, there would be nothing to prevent measures being taken to exclude most of the water from the depression except what would be required for the irrigation of reclaimed areas, and evaporation gradually reduced the area of the lake until it reached the present dimensions of the modern Birket Qarun. Much discussion has taken place within recent years with regard to the project of restoring this great storage reservoir. To enlarge the Bahr Yusef and flood the Fayûm involves the loss of many thousand acres of rich land; hence Captain Whitehouse proposed to utilise another depression, the Wady Ryan, lying to the south and south-west.[3]

The Birket Qarun lies approximately 140 feet below sea-level, and has an area of about 87 square miles, being 25 miles long and 5 or 6 miles in maximum breadth; the maximum depth is about 25 feet. The water of the present lake is sufficiently brackish to be quite unpalatable, though it is quite good enough for most culinary

[1] Apostolidis (*Bull. Soc. Khédiviale de Géogr.*, ser. vii., 1908, pp. 109 *et seq.*) maintains that this is a mistake made originally by Herodotus, and contrary to the testimony of monuments, traditions, etc. He says Regnant's analysis shows that the water is too salt to serve for agricultural purposes, and that there is no reason to suppose that in antiquity things were different. The principal canal of the Fayûm was made of such a depth that the waters of the Nile might freely enter the province even in low flood, and subsequently a lake was made at the entrance to the Fayûm to act as a reservoir for the superfluous waters at periods of high flood, for purposes of agriculture.

[2] *The Fayûm and Lake Moeris*, p. 78, London, 1892.

[3] See William Willcocks, *The Assuân Reservoir and Lake Moeris*, lecture delivered before the Khedivial Geographical Society at Cairo, London, 1904.

purposes; its density is slightly above that of fresh water, and the proportion of soluble salts about one-fourth of that in the ocean. At the west end of the lake, where the concentration is greatest, owing to the distance from the feeder canals, the proportion of soluble salts is 1·34 per cent., of which 0·92 per cent. is sodium chloride. Schweinfurth[1] shows that the degree of concentration of salt in a lake the volume of which has been continually reduced, and to which salt has constantly been added, should be many times greater than this amount, and concludes that the lake must have a subterranean outlet. Temperature observations gave a maximum of 94°·2 Fahr. (34°·5 C.) in shallow water close to the shore about 2 o'clock on an afternoon in May 1907, and a minimum of 54°·8 Fahr. (12°·2 C.) at the surface in the early morning. One series gave a difference in temperature of 12°·4 Fahr. between the surface and a depth of 3 fathoms; another gave a difference of 8°·8 Fahr. between the surface and a depth of only 1 fathom.[2] There is a great quantity of life in the lake, belonging to comparatively few species.

The lakes occupying the so-called Great Rift Valley in East Africa, an inland drainage area extending from the Red Sea to south of the equator and covering an area of about 50,000 square miles, should be referred to here, but it has been found more convenient to deal with them after describing the lakes of the Zambesi basin (see pp. 606 and 618).

North America.

The inland drainage areas of North America (Great Salt Lake area, Central America, and Mexico) are estimated by Murray to cover 278,000 square miles (see fig. 66).

Great Salt Lake area.

West of the Wasatch Range and the Colorado plateaus, south of the Columbia plateaus, and east and south of the Sierra Nevada, there is an arid region embracing all of Nevada, part of Utah and Arizona, and the south-eastern corner of California. Humid air-currents travelling eastward from the Pacific suffer a condensation of their vapour before reaching the basin, so that they arrive as drying winds. This region is diversified by many independent mountain ranges of north-and-south trend and of varied structure, uniting to form troughs, the floors of which sometimes stand at altitudes of from 4000 to 6000 feet, as in Utah and Northern Nevada. In the south-west the floors of the depressions are at moderate altitudes; and in two localities, one in southern Nevada — Death Valley—

[1] See note by Dr Schweinfurth on "The Salt in the Wadi Ryan" in Willcocks, *Egyptian Irrigation*, Appendix II., pp. 460–465.

[2] W. A. Cunnington, "Description of a Biological Expedition to the Birket el Qurun, Fayûm Province of Egypt," *Proc. Zool. Soc. London*, 1908, p. 3. Hitherto this lake has been known as the Birket el Qurun, but Dr Cunnington informs us that according to Captain Lyons the official spelling is now Birket Qarun.

and the other in south-eastern California, the arid floors of the deserts descend 300 feet beneath sea-level. An outflowing branch of the Colorado in time of flood occasionally turns northwards on reaching the delta, and flows into the latter depression, forming a short-lived lake. Sometimes the valleys are filled for a thousand feet or more with rock waste; some of the gently inclined slopes

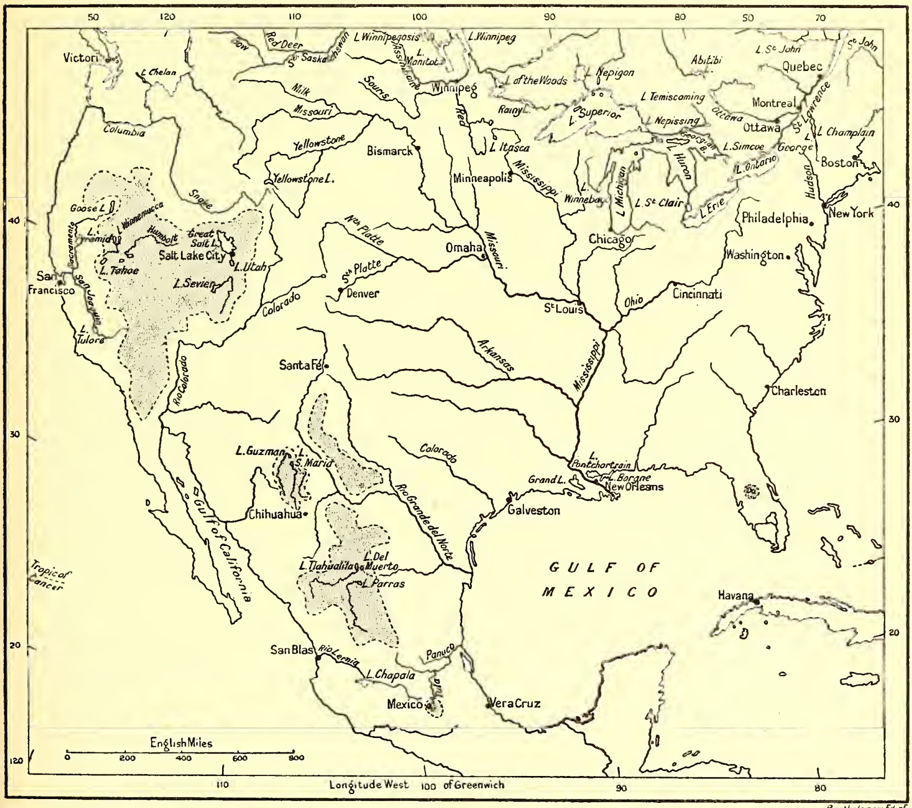

FIG. 66.—Inland drainage areas of the Great Salt Lake region, Central America, and Mexico; showing also the Mississippi River basin.

[The inland drainage areas are stippled.]

at the foot of the mountains are rock-floored, bearing only a thin veneer of waste here and there. The streams issuing from the mountains after a shower find no channels, but spread out in a sheet a mile or more broad and 1 or 2 feet deep, washing the gravel veneers forward down the inclined rock-floor; this peculiar style of drainage has been termed a "sheet flood." Many small streams from the mountains dry up on the waste slopes, owing to the great evaporation; the larger ones unite to form shallow salt lakes in the lowest part of the troughs lying between the mountains. Others form shallow water-sheets, a few inches deep, in the wet season, where smooth plains of barren sun-baked mud, or "playas," remain in the dry months. The old shore-lines, marked by cliffs, bars, and deltas in the Great Salt Lake region of Utah and in north-western Nevada, indicate a past humid climate, and show that formerly these basins held large lakes that rose nearly a thousand feet on the adjoining mountain flanks.

Lake Bonneville.

The Great Salt Lake of Utah is a relic of the much larger lake which has been given the name of Lake Bonneville. In superficial area Lake Bonneville was probably nearly equal to Lake Huron, and had a maximum depth of 1000 feet. Of this pristine lake the western limit may still be regarded as undefined, though the principal divisions were probably as follows:—

(1) The main body, covering the area of the existing Salt Lake and its shores eastwards to the Wasatch Mountains, and westwards to beyond the 114th meridian.

(2) Cache Bay, covering the present Cache Valley in Utah and Idaho.

(3) Utah Bay, occupying the valley of the present Utah Lake in the east-central part.

(4) Sevier Bay, and (5) Escalante Bay, both to the south.

The topographical elevations of the Bonneville area, once existing as islands and archipelagoes, now appear as hills and mountain spurs, with valley passes in place of the old-time straits. On the Great Desert the hills are half buried in lacustrine sediments, and rise from the lake-floor as sharply as do the present islands from the water-level of the Salt Lake.

As the waters of Lake Bonneville fell, the lake was divided into separate bodies, and the after-history of each lakelet was determined by its own conditions of local supply and evaporation. In many of the lakelets evaporation has resulted in complete desiccation, and in the deposition of rock-salt, usually associated with gypsum. The gypsum is occasionally found as small free crystals, which on the Sevier Desert are drifted by wind action into great glistening dunes. Professor Russell estimates that the dunes in one locality contain about 450,000 tons.[1]

Most of the Bonneville lakes are alkaline, or salt, though a few fresh-water bodies of small dimensions do occur, including:—

Utah Lake, 27 miles long, 12 miles broad, having an area of 127 square miles. The overflow from this lake is conveyed by the Jordan River to the Great Salt Lake in Utah; hence it is fresh.

Bear Lake, discharging through Bear River into Great Salt Lake.

Among the salt and alkaline lakes of the Great Basin are:—

[1] Talmage, "Lake Bonneville," *Scott. Geogr. Mag.*, vol. xviii. p. 471, 1902.

Great Salt Lake, the density of the waters of which is 1·168; the wind alone sometimes makes a change in the level of the water of several feet, and a consequent change of density from 1·009 to 1·014 within five minutes has been observed. The water is not alkaline, but contains an excessive quantity of saline material, chiefly sodium chloride.[1]

Sevier Lake in Utah, the waters of which are intensely saline, is virtually a "playa"[2] of variable dimensions, attaining in humid seasons an extent of from 180 to 200 square miles, while during periods of drought it practically dries up, leaving a crystalline bed of sodium chloride and sodium sulphate to mark its site.

Soda, Walker, Winnemucca, and Pyramid Lakes in Nevada; Albert Lake in Oregon; Mono Lake and Owen's Lake in California, also belong to this category.

Great Salt Lake of Utah, 4200 feet above sea-level, about 75 miles long by 50 miles in maximum width, lies at the western base of the Wasatch range, from which it receives numerous streams. The inflow to the lake is variable in amount owing to irregularity in rainfall, and as evaporation, the only means of discharge, is uniform, the lake is subject to fluctuations in area and volume. The lake-bed is shallow and the shores quite flat, so that a slight reduction in water-level causes a notable diminution in the area of the lake, which has varied from 1750 to 2000 square miles.

Evaporation from the surface of the lake must be enormous. It has been estimated, from a calculation of the area of the evaporating ponds used in preparing salt from the waters of the lake, and of the amount discharged into them by the pumps per day, that the evaporation from the lake-surface during at least three months of the year may represent about 11,424 million gallons of water per day. In a paper entitled "Why the Salt Lake has fallen,"[3] Murdoch says that the fall in the Salt Lake (1903) appears to have been due to a combination of shortage in precipitation and loss of water through irrigation, but that the shortage in precipitation is undoubtedly the predominating factor.[4] The soil in the drainage basin of the Great Salt Lake is generally a sandy loam, which would favour rapid per-

[1] See second footnote on p. 515.

[2] Saline lakes of arid regions, where the mean annual influx and the mean annual loss by evaporation are nearly evenly balanced, frequently disappear entirely during the hotter portions of the year, leaving behind wide mud plains, called "playas." The temporary lakes to which the playas owe their origin are called "playa lakes."

[3] *Nat. Geogr. Mag.*, vol. xiv. p. 75, 1904.

[4] Figures showing the average precipitation, and the rise and fall of the lake, for a certain number of years will be found in the *Monthly Weather Review*, vol. xxix. p. 23, Washington, 1901.

colation, but not very rapid evaporation. Irrigation would produce a decreasing fall every year until a balance should be reached between the area of the lake and the amount of water it received, when no further fall would occur as the result of irrigation. Irrigation was in progress during the time that the lake rose rapidly. Talmage says that in the dry atmosphere of the Great Basin much of the water spread upon the land is lost from the surface by immediate evaporation, and little water finds its way to the lake through subterranean channels or by springs.[1] But a small portion of the water lost by evaporation within the area is precipitated again therein, the prevailing winds operating to carry it eastward. The rise in the lake-level which began after the first settlement of the region was in part due to the pasturing of animals in large numbers within the drainage basin. The effect was that the soil was trampled down, and by thus losing in surface porosity it permitted the water to run directly off, and the lake was the recipient of greatly increased contributions. The removal of the herbage by cattle, and the deforesting of the hill-slopes by man, further lessened the retention of rain-water and snow within the region.[2]

Lake Lahontan.

Honey Lake, California; Pyramid, Winnemucca, Humboldt, North Carson, South Carson, and Walker Lakes, Nevada, occur in valleys which are deeply filled with the sediment of another ancient body of water named Lake Lahontan.

Honey Lake, the western arm of Lake Lahontan, may be classed to-day as a playa lake; it is without outlet, and becomes completely desiccated during seasons of unusual aridity.

Pyramid Lake, 4890 feet above sea-level, is 30 miles in length by 12 miles in maximum breadth; its area in September 1882 was 828 square miles. The greatest depth is 361 feet. As the Lahontan beach is 525 feet above the 1882 level of Pyramid Lake, the former lake had a depth of 886 feet; this is the deepest point in Lake Lahontan. Pyramid Lake is without outlet, and receives almost its entire supply from the Truckee River, which enters it at the southern end. Near the mouth of the Truckee the waters are sufficiently fresh

[1] Talmage, "The Great Salt Lake," *Scott. Geogr. Mag.*, vol. xvii. p. 630, 1901.

[2] See Trimmer, "Rise in the Level of the Great Salt Lake," *Geogr. Journ.*, vol. xxxi. p. 568, 1908. The level of the Great Salt Lake at midsummer 1907, after the snows had melted on the mountains, was 3 feet 6 inches above zero, the highest reading for ten years. A railway was built on piles during the low-water period for a distance of 10 miles across the shallows of the northern end of the lake, at a height supposed to be beyond the reach of the water, but a further rise of 2 feet would submerge the rails. Bearing in mind the steadily increasing diversion for irrigation of all streams feeding the Great Salt Lake, the rise now under observation seems to be of unusual interest.

to be used for camp purposes; at the northern end it is too saline and alkaline for human use, but is used as drinking-water for cattle.

Winnemucca Lake, 3875 feet above sea-level, 26 miles long, with an average breadth exceeding 3½ miles, is also fed by the Truckee River, and has no outlet. As in the case of Pyramid Lake, nearly all the water-supply enters at the southern end, so that this portion is fresher than the northern.

Humboldt Lake, about 4200 feet above sea-level, is but an expansion of the river that supplies it, and is held in check by an immense gravel embankment that was thrown completely across the valley by the currents of the former lake, at one time 500 feet deep at this point. The embankment has been cut across by the overflow of the lake, but the breach has been partially filled during the past few years by an artificial dam, which has greatly increased the area of the lake. During the dry season the lake seldom overflows, and is then the limit of the great drainage system of the Humboldt River; but in winter and spring the waters escape southwards and, spreading out on the desert, form Mirage Lake. Farther south, in the northern part of the Carson Desert, they again expand and contribute to the formation of North Carson Lake.

North and South Carson Lakes are shallow playa lakes in winter and spring, and in arid summers they evaporate to dryness.

Walker Lake, 4147 feet above sea-level, is about 25 miles in length by 5 miles in breadth, and has an area of 95 square miles. A remarkably uniform depth of 224 feet was found over a large area in the central and western portions.

Lake Tahoe,[1] "the gem of the Sierra," finds an outlet through Truckee Cañon into Pyramid and Winnemucca Lakes, 2400 feet below. It is a mountain lake situated about 1000 feet above any traces of Lake Lahontan, at a height of 6234 feet above sea-level, and the boundary-line between California and Nevada passes through it in a north-to-south direction near its eastern shore, so that a little more than two-thirds of its area lies in California. The thirty-ninth parallel of latitude crosses the southern end of the lake, and the longitude is 120° W. The lake occupies an elevated valley on the humid forested summit range of the Sierra Nevada Mountains. The length is about 22 miles, the greatest width about 12 miles, and the area about 193 square miles. Comparatively few soundings have been made in the deeper water, and the greatest known depth is 1645 feet. Affluents are numerous, especially in summer, when the snow on the neighbouring mountains is melting rapidly, the largest being the Upper Truckee River; the outlet is also known as Truckee River. On 17th

[1] See C. Juday, "Studies on some Mountain Lakes," *Trans. Wisconsin Acad. Sci., Arts, and Letters,* vol. xv. p. 790, 1907.

June 1904 the temperature of the surface water was 60°·8 Fahr. (16° C.), and of the bottom water, where the depth was only about 427 feet, 40°·2 Fahr. (4°·9 C.). In August 1873 Le Conte[1] found the temperature of the surface water to be 66°·9 Fahr. (19°·4 C.), falling to 41° Fahr. (5° C.) at 772 feet, and to 39°·2 Fahr. (4° C.) at the bottom in about 1506 feet. The winters in this region are usually severe, so that the air probably remains far below the freezing point for a considerable period each year. Notwithstanding this fact, however, ice never forms on the lake except in the shallow bays. The water is very transparent; a Secchi disc just disappeared from view at a depth of 66 feet (20 metres). When most of the snow has disappeared the transparency is said to be much greater, white objects being easily seen at a depth of more than 98 feet, and Le Conte records that in August 1873 he found that a white plate was still visible at a depth of 108 feet.

Mexico and Central America.

Mexico contains two types of inland drainage areas. The most interesting is that in the volcanic highlands of Anahuac, in the latitude of the city of Mexico, where the lakes are enclosures in the irregular topography of the piled-up volcanic material; but this is now no longer a true inland drainage area, for by means of immense artificial water-ways the lakes lying within the depression have been made to drain, as we shall presently have occasion to point out, with some detail, into the Gulf of Mexico. The principal lakes of this area are Tezcuco, near the shores of which the city of Mexico now stands, and Chalco. Both are noteworthy for their magnificent scenery, surrounded as they are by volcanic peaks and extinct craters of great height; but they, like the other lakes in the same basin, have shrunk greatly in size. The depth of water in Lake Tezcuco at the present day under normal conditions hardly exceeds 2 feet over a large part of its area.

The ancient town of Tenochtitlan, formerly standing on the site of the modern Mexico (7524 feet above sea-level), was actually founded in the lake, like another Venice, cut up by canals and connected with the shores by narrow viaducts and bridges. It was built there by Aztec immigrants in order that they might defend themselves against surrounding enemies; but, on gaining power and riches, they set to work trying to drive back the waters from their city by means of great dams, and thus free themselves from the danger of destruction by floods. They were only partly successful in this. After the complete destruction of the city at the conquest in 1521, Cortez built up the city of Mexico on the ruins of Tenochtitlan; and, partly by means of dams, partly by the turning aside of streams, Mexico

[1] Cited by Juday, *op. cit.*, p. 791.

ceased to be a lacustrine city, and many of the surrounding swamps disappeared; but irregularities in the level of the lake, and the stagnation of sewage waters, made the town very unhealthy. A plan of drainage for remedying this state of affairs was begun in 1607 under the direction of Enrico Martinez, but for various reasons it was not carried out successfully, and in 1629 the city was overwhelmed by a disastrous flood. Of the 20,000 families who had their homes in the city, only 400 survived. For a time it was thought that Mexico should be abandoned, and that Puebla should be made the capital in its stead; but the plans of drainage were carried on for years without much method, and Mexico still held her position as capital of the country. The canals of drainage were not completed till towards the end of the nineteenth century, and were then not carried through the old cuttings, but were formed farther to the east. This *desague*, as the work is called, is the greatest drainage system and one of the most remarkable engineering enterprises in the world. It consists of a canal 43 miles in length, and a tunnel somewhat exceeding 6 miles, and it carries off the surplus waters of the whole Mexican basin into the River Tequizquiac, a tributary of the Tula, whence they flow by the Rio Panuco into the Gulf of Mexico. Partly as a result of this draining off of the waters of the lake, and partly as a result of a general desiccation of the surrounding regions, the lake has withdrawn, till now over two miles intervene between the lake-shores and the city.

The other inland drainage area lies north of the volcanic highland, and has been termed the Chihuahuan province of the great American desert, in contradistinction to the Soñora Nevada province to the west of the Western Sierra Madre. The lakes of this province are all of the ephemeral desert type. During the rainy season the waters which find no seaward outlet are collected in depressions on the plateaus, where extensive tracts, known as lagunas, remain flooded for several months at a time. But the waters are rapidly reduced in level by evaporation, and fluctuate greatly with the quantity of rainfall. At a very early period, when the rainfall of the country was greater, there was, according to Reclus,[1] an excess of water, which found its way to the course of the Rio Grande del Norte by valleys, where it is still possible to follow with the eye the old river-beds. Then, as precipitation became less, the outflow ceased, and the waters of the basins thus cut off gradually became salt. Many lakes have been entirely dried up, owing to the fact that the streams which fed them were lost through evaporation in the desert before reaching them. One reason given for this process of desiccation is the reckless destruction of the upland forests by

[1] *Le Mexique au début du xx^e^ siècle*, p. 55, Paris, N.D.

European settlers. Another,[1] recently advanced, is that the rivers which have their origin in the humid, wooded tops of the higher areas erode away the margins of the rain-collecting highlands in their descent towards lower and more arid levels, and gradually diminish as they destroy their rain-collecting areas.

The chief lakes of the basin in the Durango district are:—Laguna de Tlahualila, which receives no streams of any size; Laguna del Muerto or Mayran, which receives the waters of the River Nazas; and Laguna Parras, into which flows the Aguanaval. These all lie comparatively close together, and none of them has an outlet. The fact that there exist in the River Nazas species of fish which occur also in the Rio Grande is further proof of the former existence of a connection between these inland basins and the Rio Grande.

The same conditions continue northward into Chihuahua, New Mexico, and Western Texas, which receive the drainage of the plateau of the Sierra Madre. The lakes in this area are comparatively small. The two principal ones are Laguna de Guzman, into which flows the River San Miguel, and Laguna de Santa Maria, into which drains the river of the same name.

In Central America lakes without outlet are common in the limestone region of Northern Guatemala, the largest being Lake Peten, and in the rainy season many shallow temporary lakes (*akalches*) are formed in the hollows of the same region. Numerous lagoons of brackish water lie along both coasts.

SOUTHERN HEMISPHERE.

This concludes our survey of the lakes situated in the inland drainage areas or desert regions of the Northern Hemisphere. When we turn to the similar areas of the Southern Hemisphere we find that, because of the less developed land-masses, these areas are—excepting Australia—very limited in extent when compared with their northern analogues.

Australia.

Australia may be described as a plateau fringed by well-watered coasts, with a depressed, and for the most part arid, interior. Nearly two-thirds of the inland drainage area of Australia, which is estimated by Murray at 1,556,000 square miles (see fig. 67), is occupied by the Great Austral Plain, flanked on every side by mountains and table-lands, and sloping more or less gradually to a central depressed lake region. The plain is subdivided by undulating downs, or flat-topped hills, with here and there some scattered mountain groups. Where the rainfall is not all absorbed by the soil or lost through evaporation, the depressions are occupied by saline[2] lakes.

[1] R. T. Hill, "Characteristics of some Mexican Mining Regions," *Engineering and Mining Journal* (New York), vol. lxxxiv. p. 633, 1907.

[2] See second footnote on p. 515.

What is known as the lake area is a district north of Spencer Gulf covered with several expanses of brackish water that contract or expand as the season is one of drought or of rain. In seasons of drought they are hardly more than swamps or mud-flats, which for a time may become grassy plains, or desolate shores encrusted with salt; in the wet season they receive the waters of a vast extent of country, including streams from Western Queensland.

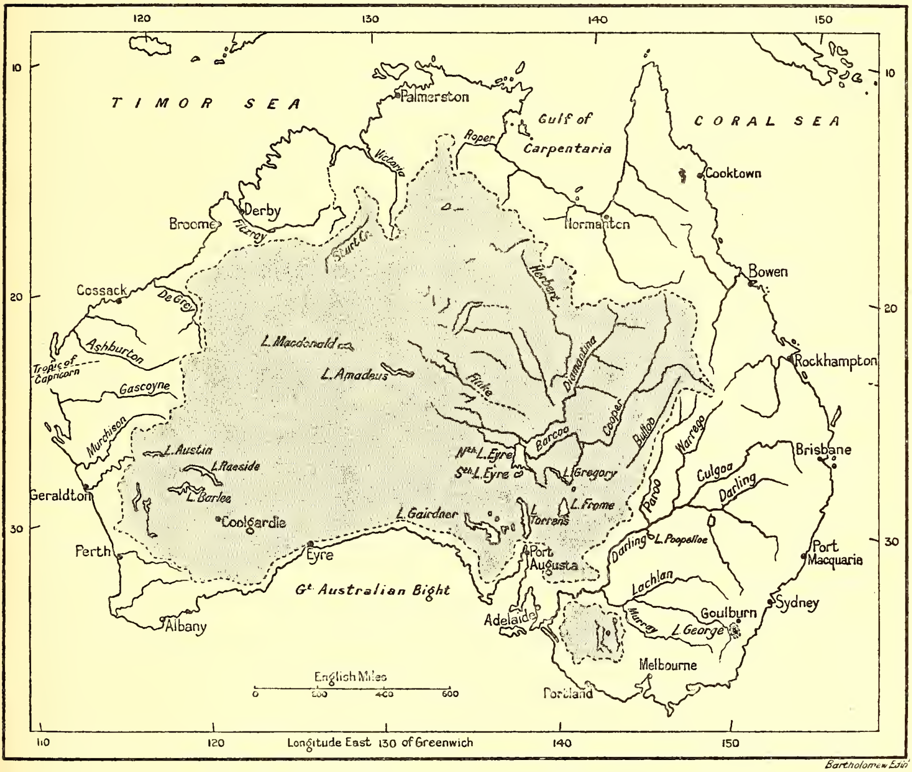

FIG. 67.—Inland drainage areas of Australia.
[The inland drainage areas are stippled.]

The rainfall being very irregular, sometimes the rivers rush down in flood, carrying torrents of water to the lakes, while at other times they are dry for months. Many of the rivers draining inland lose themselves in the interior; they carve out valleys, dissolve limestone, and spread out their deposits over the plain, when the waters become too sluggish to bear the burden further.

Lake Eyre and **Lake Torrens**.—North of Spencer Gulf lies Lake Torrens, sometimes 100 miles in length, and north of that again stretches Lake Eyre, 80 miles long by 40 miles broad, covering an area of about 3200 square miles. The two lakes are divided by a ridge of hills to the north of Lake Torrens, with only one low gap in the divide, at a height of 175 feet above sea-level. Lake Eyre receives the water drained from 500,000 square miles of country, and it absorbs it all, for the lake has no outlet. The region has a soil of exceptional richness, an invigorating climate free from malaria and other diseases incidental to most subtropical lands, and given water the country would be fertile as a garden. To effect this it was proposed to cut a canal from the sea at Port Augusta to Lake Eyre, and so flood its vast basin with sea-water, thereby lowering the temperature and increasing the rainfall and the dew. Gregory [1] says this is possible, but the length of the canal would be 260 miles, and as the lake-surface is 39 feet below sea-level, the fall would be little more than an inch to the mile. The channel would have to be cut to a depth of 100 feet for 200 miles, and in one place to 200 feet, and it would have to be large enough to keep pace with the loss of water from evaporation. That this loss would be heavy is evident from the fate of the floods that are carried into Lake Eyre by the Diamantina and the Cooper or Barcoo Rivers. The quantity of water these rivers discharge is enormous, and yet no man has ever seen the lake full or nearly full, so that a sluggish 50-feet canal would not be very successful, and would probably lead to the choking up of the whole lake-bed within thirty years with salt, like a salt-pan, through evaporation, which in the Lake Eyre country is, according to Sir Charles Tod,[2] 100 inches a year, and even sometimes as much as 1 inch per day.

The wind which sweeps across the central plains of Australia has dropped its moisture as rain on the highlands near the coast, and is therefore dry, and capable of absorbing an unusually large amount of moisture. The evaporation from the water-surface of Lake Eyre is said to be equal to from fifteen to twenty times the rainfall.[3]

The evidence is very conclusive that the Lake Eyre region was formerly one of great fertility. At one time it was evidently a vast inland sea. Round such a sheet of water there must have been a heavy dew, and probably the rainfall was also considerable, for the adjacent steppes were well grassed and fertile, and large trees, now represented by their petrified trunks, grew on the plains. The waters of this lake were fresh, and it was about three times the size of the present one. The rainfall dwindled, the water-level sank, and the lake decreased in size. The discharge from the lake was no longer sufficient to keep open its channel, which the warping of the surface and the accumulation of debris continually tended to close.

There is no outlet from the deep central basin of the Lake Eyre

[1] See *The Dead Heart of Australia*, pp. 345 *et seq.*, London, 1906.

[2] Cited by Gregory, *op. cit.*, p. 347.

[3] Gregory, *op. cit.*, p. 325.

country. It is enclosed by a rim of old rocks, which, so far as we know, is complete to the west and south, and has only a narrow, shallow lip to the north, and perhaps another to the east, so that there is no escape for a subterranean river. Wells have been bored, and furnished an abundant supply of water. The high temperature gradient, and the occurrence of free gases in the wells, indicate that the water rises from great depths. Again, the decrease in the yield of many of the wells shows that they are the modern artificial outlets from a vast reservoir, or underground terminal lake, the waters of which must have been collected during the course of centuries.

The water from the artesian wells is mainly used for watering stock. The irrigation of ordinary crops in an arid country consumes a large amount of water, and the areas which could be irrigated from the wells are small in comparison with that which must lie idle. Henderson [1] estimated that under the most favourable conditions, and even if the water were lost neither by soakage nor by evaporation, only the three-hundredth part of the western districts could be irrigated. Again, the artesian waters are not always suitable for irrigation, being highly saline, and especially apt to be charged with carbonate of soda. Luxuriant crops are produced for the first few years, but the evaporation of the water leaves a deposit of carbonate of soda, which is very injurious to the growth of the plants.

Lake George, the largest lake in New South Wales, is 25 miles long, 8 miles broad, and lies at an elevation of 2100 feet above sea-level. It occupies an area of subsidence in the Blue Mountains, about 135 miles to the south-west of Sydney, bounded by a fault plane of about 400 feet drop. It is not always a lake, for at intervals it shrinks for years and finally becomes dry, when it is portioned into grazing leases, fences running nearly across the bed, and it yields very good pasturage for sheep. The basin of Lake George contained water in the years 1816–1830, 1852 (when it attained its maximum depth of rather more than 10 feet), 1864, and 1874–1900; it was practically dry again by 1905. It occupies the southern portion of a depression in the Cullarin Range called the Lake George Depression, 490 square miles in extent, and the only example in New South Wales of a purely inland drainage area. It is watered by several small streams, but has no visible outlet. Taylor [2] corroborates the theory that the lake never had an outlet; no evidence of a flood more than 30 feet deep can be traced as having occurred for many centuries, while nearly 200 feet are necessary to provide an outlet north, west, or south. Probably since its inception the lake has been receiving silt, which has gradually filled up its bed. A local flood has no

[1] See *Seventeenth Ann. Rep. Hydraulic Engineering*, p. 16, Brisbane, 1901.

[2] *Proc. Linn. Soc. N.S.W.*, vol. xxxii. p. 335, 1907.

effect on the lake, the dry silt acting as a sponge. The conditions are extremely favourable for great evaporation. The wind may drive a layer of water several miles from the actual lowest spot, and before it can flow back the sun's heat has reclaimed it for the atmosphere.

Lake Bathurst, lying about 12 miles east of Lake George, has an area of 5 square miles when full, but like the latter it sometimes dries up entirely. Taylor[1] is of the opinion that in earlier geological periods the Mulwaree Creek, which drains a fairly large basin and flows past Lake Bathurst about half a mile to the west, received two tributaries, one from the north-east and the other from the south-east, both of which crossed the bed of the present lake. In periods of drought these lateral streams probably ceased flowing, with the result that their entrance to the main stream became blocked by material washed down by the Mulwaree, and a lake was formed. In 1844 the lake was dry; in 1873 it overflowed into the Mulwaree; in 1890 it was within a few feet of overflowing; in February 1907 only a quarter of its bed was covered, and the maximum depth was not more than 1 foot. Taylor found the ground at the east end of the lake littered with the bodies of tortoises which had been driven from the lake by the increasing salinity, and as there is no permanent water on the eastern shore, they perished. He suggests that in some such way many of the huge deposits of fossil vertebrates found in various parts of the world took their origin.

SOUTHERN AFRICA.

The inland drainage area of Southern Africa has been estimated by Murray to exceed 110,000 square miles (see fig. 68).

Kalahari Desert.

The Kalahari extends north from the Orange River as far as Lake Ngami, and is situated in the two divisions of South Bechuanaland, now incorporated with Cape Colony, and North Bechuanaland, a British protectorate. It is regarded by many as a very old accumulation of wind-blown sand; Livingstone,[2] on the other hand, spoke of the decrease of precipitation over the Kalahari in historic times, and considered that the Central and Northern Kalahari was formerly a lake. He went still further, stating that the manner in which the Zambesi River breaks through the hilly land at the Victoria Falls led him to think that the river probably cut down the barrier of the former lake, and thus drained it. Passarge[3] recounts the following evidence given by Livingstone as to the drying up of the Kalahari region:—The River Kolobeng, once rich in fish, dried up in Livingstone's time, and has had no water since. Lopepa, in Western Bamangwátoland, was at the time of his first visit a large pool of

[1] *Op. cit.*, p. 344.

[2] See *Missionary Travels and Researches in South Africa*, p. 527, London, 1857.

[3] See *Die Kalahari*, pp. 98–103, Berlin, 1904.

water, from which a stream flowed towards the south; on his second visit he could only find water by digging.

The Kalahari region includes several secondary basins—wide depressions partly crossed by river-courses, partly occupied by lakes

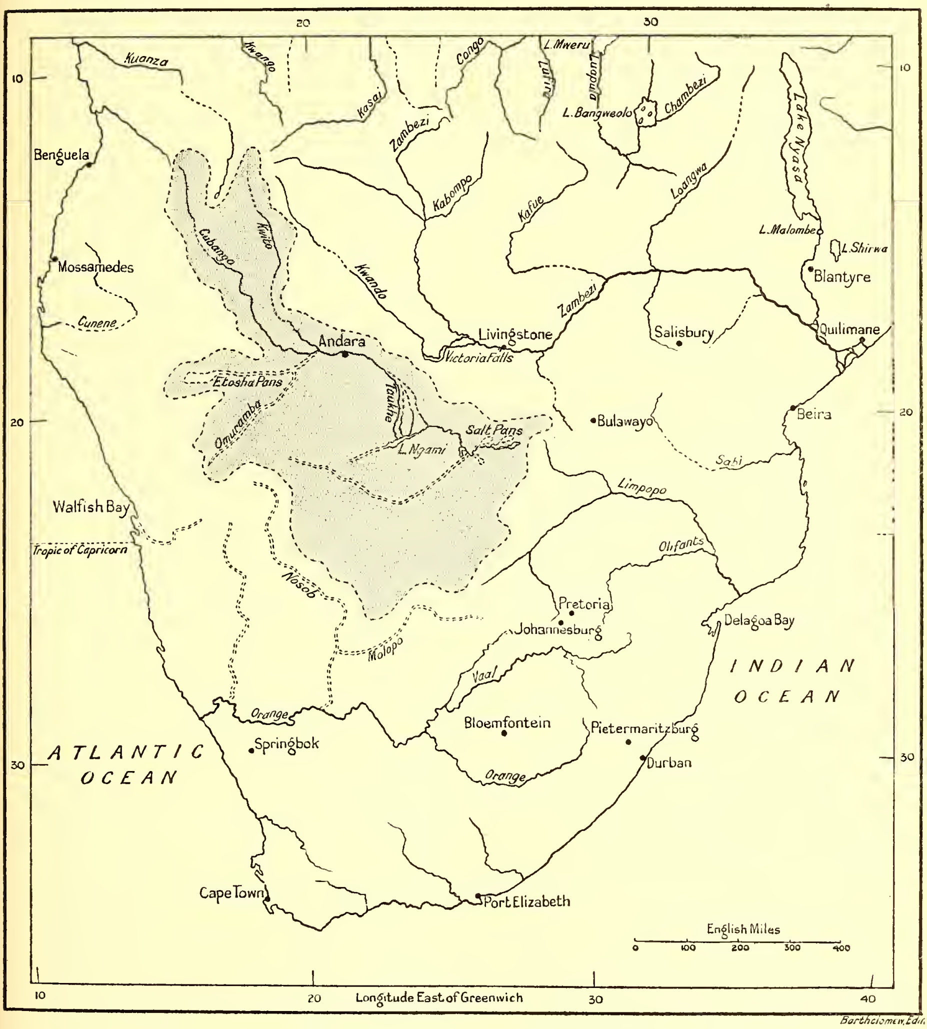

FIG. 68.—Inland drainage area of Southern Africa (Kalahari).
[The inland drainage area is stippled.]

and marshes. These basins are separated by even stretches of rising ground, which here and there form connected ridges. While the bottom of the basins is covered with recent sand, the ground rock crops out in places on the ridges, and these places are of great importance, for there good water is found either as springs or in chalk-pans—

flat chalky surfaces surrounded with sand—and therefore all the traffic routes pass through them.

Lake Ngami[1] is the central point of an inland water-system of South Africa, in lat. 20½° S., long. 23° E., at an altitude of about 3000 feet above sea-level. The lake was once 20 miles long and 10 miles wide, but is now dry, consisting merely of an expanse of reeds growing in a soft, treacherous soil, below which brackish water is found at a depth of 20 feet. The former feeder of the lake was the Taukhe or Tiohge River (known in the upper part of its course as the Okavango or Cubango River), which entered at the north-west end, but now a portion at least of its waters passes by a channel north of Lake Ngami into the Botletle or Zuga River, by which the overflow of the lake was formerly carried off eastwards at the time of high water. The Botletle River loses itself in a system of salt-pans—round or oval basins of varying size sunk to depths of 30 to 45 feet in the sandstone, and often bounded by steep banks. The largest of these is the salt-pan called Makarrikarri. The outer pans are dry for a large part of the year, the whole system being filled only at the height of the flood season in August.

The lowest twenty miles of the Taukhe River are said to have been dry since about 1890, the district intersected by the river-beds now growing corn in great plenty. The cessation of the river's flow was caused, according to native report, by a blocking of the channel by thousands of rafts, on which the Makoba natives brought down their yearly tribute of corn.

Precipitation is greater in Northern Kalahari than in the southern and central portions. In the former the river-courses are marshy even in the dry season. Flooded plains still hold a little water at the end of the dry season, and sand-pans with permanent ponds are not uncommon. In Southern and Central Kalahari the salt-pans contain water only in the rainy season; at other times they dry up and leave behind a crust of salt.

Underground water does not exist to any extent in the Kalahari as in the Sahara. In the dry regions the scanty rainfall is absorbed by the sand, and evaporates in the long dry season; in the alluvial regions underground water is comparatively small in quantity, for the steep crumbling ground-rock does not form a good water-way.

SOUTH AMERICA.

The inland drainage areas of South America are estimated by Murray at over 500,000 square miles (see fig. 69).

According to Neveu-Lemaire,[2] the region of South America lying

[1] See *Encycl. Brit.*, ed. 10, vol. xxxi. p. 228; see also note on Dr Poch's expedition, *Geogr. Journ.*, vol. xxxiii. p. 601, 1909.

[2] See "Le Titicaca et le Poopo," *La Géographie*, vol. ix. p. 409, 1904.

between the 11th and 24th degrees of latitude, to the west of the Cordillera of Los Frailes, has a mean altitude of 13,123 feet (or about $2\frac{1}{2}$ miles), and has no outlet for the waters that accumulate in it. Locally it is called the "puna," and in some parts there occur immense saline plains (*pampas salinas*), while in others are vast deserts with- Peru and Bolivia.

Fig. 69.—Inland drainage areas of South America.
[The inland drainage areas are stippled.]

out trace of vegetation. Not a single tree is found throughout the whole region, though in some parts plants of the cactus tribe are sparsely distributed. The drainage accumulates in the two lakes Titicaca and Poopo; but while the former is deep, contains fresh water, and is surrounded by lofty mountains, Lake Poopo is a great shallow lagoon containing salt water. The two are connected by the Desaguadero, which flows from Titicaca into Poopo. Lemaire says that both lakes are remnants of a vast inland sea, which once existed in this region, extending from lat. 15° to 21° S., and draining by a large river into the basin of the Amazon. Both lakes have been rapidly drying up within historic times. The old temple, which was once on the shores of Titicaca, is now a considerable distance away from it, and some height above the level of the waters. Sir Martin Conway[1] says that somewhere on the borders of Bolivia and Chili, at an altitude of 17,000 feet, are the remains of cultivated fields now abandoned. In South America no fields at a height of 17,000 feet can be cultivated, so that the abandonment of these fields was due to the great increase in elevation that had occurred within historic times in the district. This increase in elevation appears to apply, according to Sir Martin Conway, to the central belt of plateau that runs north and south through a considerable part of South America. Along the Peruvian slope shells of existing species are found on the hillsides at an altitude of 1000 or 1500 feet, and even, according to some authorities, as high as 3000 feet. The increasing desiccation of the plateau is due to that rapid elevation. The moisture comes in a steady drift from the east over the great Amazon plain, and is precipitated upon the mountains. As the mountains increase in altitude, and the belt of mountainous country widens, the rainfall on the actual plateau diminishes.

Lake Titicaca is situated between lat. 15° 20′ and 16° 35′ S., and between long. 68° 15′ and 69° 40′ W. It is the highest lake of America, lying 12,500 feet above sea-level. Its length is 120 miles, its maximum breadth 41 miles, and its area about 3200 square miles, exclusive of islands. About 120 soundings were taken by Neveu-Lemaire,[2] the Belloc sounding machine being employed whenever the depth was greater than 32 feet. In his bathymetrical map the contours of 25, 100, and 200 metres (82, 328, and 656 feet) are drawn in. The deepest area lies towards the north-east shore, the contour-line of 200 metres approaching comparatively close in two places, while on the opposite side a wide band of regular width, with depths of 100 to 200 metres, runs parallel to the south-west shore. Soto Island, the midmost island in the lake, rises abruptly from the deepest part, 270 metres (886 feet) being found at a little distance from its south end on the landward side, while the maximum depth got by Lemaire (272 metres or 892 feet) was found abreast of the island on the major axis of the lake.[3] The "Little Lake," joined to the "Great

[1] See discussion on the desiccation of Eur-Asia, *Geogr. Journ.*, vol. xxiii. p. 736, 1904.

[2] See Neveu-Lemaire, *Les lacs des hauts plateaux de l'Amérique Sud*, Paris, 1906.

[3] Agassiz gives 154 fathoms (924 feet) as the maximum depth ("Hydrographic Sketch of Lake Titicaca," *Proc. Amer. Acad.*, vol. xi. p. 283, 1876).

Lake" in the south by a strait, is shallow, though the strait itself is fairly deep. A considerable portion of the floor of Lake Titicaca lies at a lower level than that of Lake Poopo, the very shallow lake into which its waters overflow. The water of Lake Titicaca is comparatively fresh, containing only 0·11 per cent. of solid matter in solution.

Observations of much interest were obtained regarding the temperature of the water in early winter, though the stay was not long enough to throw light on seasonal variations. The surface temperature was found to rise as a rule until 3 p.m., and then to fall again; but the greatest variation observed in a single day was 2°·8 Fahr., and this at a part of the lake where the depth varied greatly. The lowest surface temperatures observed naturally occurred in the shallow bays.[1] The figures relating to the bottom temperature are striking from their great regularity, in spite of great differences of depth. The extreme range was only 3°·6 Fahr. (from 48°·9 at 10 feet to 52°·5 at 60 feet). Below 240 metres (787 feet) the temperature was constant at 50°·8 Fahr. (10°·4 C.) A series of vertical temperatures near the centre of the lake showed a difference of only 1°·7 between the surface and the bottom. A. Agassiz, in his hydrographic sketch of Lake Titicaca, says the usual difference between the surface and the bottom, even at the greatest depth (154 fathoms), was not more than from three to four degrees. The lowest temperature at the bottom (in 450 feet) was 51° Fahr. (10°·6 C.), the general temperature varying from 54° to 55°; while the surface temperature ranged from 53° to 59°—the greater part of the time 56° to 57° (February 1875), the temperature of the air at noon varying from 49° to 97° Fahr.

Observations were also made on the transparency of the water, and on the climatic conditions, the flora and fauna, etc., of the surrounding country. The level of the lake rises during the summer, the amount being given as 5 inches; but apart from seasonal variation, the level is sinking progressively.

Lake Poopo (or Aullagas) lies about 387 feet below Lake Titicaca. It is irregularly oval in shape, and contains a central island (which is inhabited), as well as two islets near the western shore. The River Desaguadero enters at the north end, and has formed a delta. The lake is 55 miles in length by 25 miles in breadth, but is very shallow, two small areas in the centre alone having a depth exceeding 6 feet (maximum depth 13 feet). The water is saline and muddy,[2] and the lake is in process of disappearing, so that at no distant date it may

[1] Ward (*Science*, vol. vii. p. 28, 1898) gives two series of temperatures taken at the surface of Lake Titicaca on 26th and 28th November 1897.

[2] The water contains 2·35 per cent. of solid matter in solution, about two-thirds of that in sea-water; of this 1·68 per cent. consists of sodium chloride, and the remainder mainly of sulphates.

resemble the South Bolivian lakes, that only exist as such in the rainy season. One fish only is found in Lake Poopo, and it is believed to be identical with *Orestias Agassizi*, var. *inornata*, from Lake Titicaca. Two species of Copepoda are found in the lake, viz. *Boeckella propensis* and *B. occidentalis*.

LAKES CONNECTED WITH RIVERS FLOWING DIRECTLY INTO THE OCEAN

It has been pointed out that the meteorological conditions which generally prevail over inland drainage areas are high barometric pressure, winds blowing from off land and from colder to warmer regions, dry atmosphere, bright sunshine, few clouds, and low rainfall—consequently the maximum of insolation and terrestrial radiation.

Contrasted with inland drainage areas.

In contrast to these conditions we have those that usually prevail over the catchment basins which pour their drainage waters directly into the ocean—namely, low barometric pressure, winds blowing directly from off the ocean and from warmer to colder regions, cloudy skies, high humidity, and abundant rainfall. In the summer months of the northern hemisphere winds commencing near latitude 30° South blow home on Southern Asia as the well-known south-west monsoon of these regions. The winds of this monsoon distribute a larger rainfall over a larger portion of the earth's surface than occurs anywhere else at any season, and this rainfall is also largely increased by the mountains which lie across the path of these rain-bearing winds. Many similar, if less striking, instances can be pointed out in other regions of the world, so that in the areas now to be considered there is usually a more or less abundant rainfall; consequently all hollows or basins in the topography of these regions are filled to the rim with lakes. The outflowing rivers from these lakes ultimately, and in some instances relatively rapidly, cut down barriers, or fill up the lake-basins with detrital matter. The water in these lakes is continually being renewed, and is always fresh and drinkable. For such reasons these lakes are more uniform in character, and are probably on the whole less interesting, than those of the inland drainage areas. The salts dissolved out of the land-surfaces are borne directly into the ocean, and, accumulating there, tend to alter the composition of sea-water salts. We will review these lakes in the following order:—Europe, Asia, Africa, America, Australia, and New Zealand.

EUROPE.

Europe shows in many ways a similarity to North America in climatic, as well as in structural and topographical, features. From Scandinavia and Finland, which correspond to the Laurentian Highlands in America, extensive ice-sheets spread over the adjacent lands in geologically recent times, advancing to the south and south-eastward, leaving the land in the Scandinavian peninsula and Finland dotted with lakes, similar in origin to those north of the lake-belt in North America, and creating a new land-surface in the northern plain of Germany by covering it with glacial deposit. The ice-sheet reached to the base of the Thuringian Forest, Erzgebirge, Sudetes, and Northern Carpathians. On the southern side of the Alps an independent sheet of glacier-ice passed down the valleys, and deposited terminal moraines far out in the valley of the Po. On the northern side the ice spread across the whole of the middle plateau of Switzerland, at least half-way across the range of the Jura, and far eastward to the neighbourhood of Linz on the Danube; while to the west a glacier passed down the Rhone valley, and deposited a great terminal moraine where Lyons now stands. Among the most important evidences of this ice-era are extensive morainic deposits, either in the form of bottom moraines or terminal moraines. Such deposits abound mostly where the ice-sheets were beginning to thin out, as in the North German lake-plateau, and numerous lake-basins have been formed by inequalities in the deposition of such morainic matter. These lakes are generally of small size, and occupy either circular depressions, long narrow basins, or broad shallow basins, very irregular in outline, lying in gently undulating ground.

The most important lakes in England are those of the Lake District in Cumberland, all of which are valley lakes and occur at a comparatively low level. They were bathymetrically surveyed by Dr H. R. Mill and others in the years 1893 and 1894.[1] England.

The lakes of the English Lake District may be divided into two main types: the shallow and the deep. The former type includes only Derwentwater and Bassenthwaite Water, of which the average depth is only 18 feet. The latter type, the shallowest of which has a mean depth of 40 feet (Haweswater), comprises all the other lakes.

The fact that Derwentwater and Bassenthwaite are separated by an alluvial plain so low that their waters mingle in heavy floods shows that they may be regarded as one lake, and their configuration suggests that they may have been shallowed by glacial accumulations. Both are drained by the Derwent River, which enters the Solway Firth at Workington.

Derwentwater is a little over 2 square miles in area, nearly 3 miles in length, and has a maximum depth of 72 feet and a mean depth of only 18 feet. It lies at an elevation of 244 feet above sea-level, but this figure was given for 1893, when the level of the lake

[1] See Mill, "Bathymetrical Survey of the English Lakes," *Geogr. Journ.*, vol. vi. pp. 46, 135, 1895.

was lower than ever previously recorded; the greatest recorded range in the level of the water amounts to 9½ feet. The volume of water contained in the lake was calculated at 1010 million cubic feet, and there is a great wealth of water-plants.

Bassenthwaite Water lies 223 feet above sea-level, and covers an area exactly equal to that of Derwentwater, viz. 2·06 square miles, but it is one mile longer. The maximum depth is 70 feet, the mean depth 18 feet, and the volume of water is estimated at 1023 million cubic feet. It receives the drainage from Derwentwater and Thirlmere.

The second, or deep, type of lakes in this district are long and narrow, sometimes winding like Ullswater, sometimes slightly curved like Wastwater and Haweswater, and generally lie in long narrow valleys with steeply sloping sides, the slopes being continued under water with equal steepness, and terminating in a nearly flat bottom.

Buttermere and **Crummock Water**, 329 and 321 feet respectively above sea-level, form a double lake in much the same manner as Derwentwater and Bassenthwaite. The plain separating the two, three-quarters of a mile in length, is absolutely flat, and lies across the mouth of the lateral valley of the Mill Beck, which flows from the east and then turns abruptly northward to the lower lake, Crummock. Buttermere and Crummock Water are connected by a small stream which has been pushed over by the alluvium brought down by the Mill Beck close against the steep slope on the western side. Buttermere is 1¼ miles in length, has an area of only 0·36 square mile, a maximum depth of 94 feet, a mean depth of 54 feet, and the volume of water is estimated at 537 million cubic feet. Crummock Water is 2½ miles in length, has an area of nearly 1 square mile, a maximum depth of 144 feet, a mean depth of 87 feet, and the volume of water is estimated at 2343 million cubic feet. The outflow from Crummock Water is by the River Cocker, a tributary of the Derwent River.

Ennerdale Water may be looked upon as a combination of the deep and shallow types of lake; the best example in Great Britain being Loch Lomond. Ennerdale is a deep narrow lake, widening and becoming shallower towards its outlet, the Eden River. It lies 368 feet above sea-level, has an area of over 1 square mile, a maximum depth of 148 feet, a mean depth of 62 feet, and the volume of water contained in it is estimated at 1978 million cubic feet.

Wastwater, lying at the base of Scafell Pike and Scafell, 200 feet above sea-level, has an area of over 1 square mile, and is the deepest of all the Cumberland lakes, having a maximum depth of 258 feet, a mean depth of 134 feet, and the volume of water it contains is estimated at 4128 million cubic feet. The outflow is at the south-west end by the River Irton, a tributary of the River Esk.

Coniston Water has an area of nearly 2 square miles; the length is almost 5½ miles, but it is very narrow, the maximum breadth being under half a mile. It lies 143 feet above sea-level, and drains by the River Crake into the estuary of the Leven in Morecambe Bay. It attains a maximum depth of 184 feet, the mean depth is 79 feet, and the volume of water is estimated at 4000 million cubic feet.

Haweswater has an area of a little over half a square mile, while the length along the slightly curved axis is over 2¼ miles. It lies 694 feet above sea-level, has a maximum depth of 103 feet, a mean depth of 40 feet, and is estimated to contain 589 million cubic feet of water. From the northern shore at the mouth of the Measand Beck, a large delta, bearing upon it cultivated fields—the only arable land of the surrounding district—projects into the lake, narrowing it abruptly from half a mile to about 100 yards. Haweswater and Ullswater are the only two lakes of the Lake District having their outflow at the north-east end; their surplus waters find their way ultimately north-westwards to the Solway Firth by tributaries of the River Eden.

Ullswater, the second largest lake of the district, has an area of about 3½ square miles, and its length measured along the centre line is nearly 7½ miles. Whilst most of the other lakes have a slightly curved form, Ullswater presents two abrupt changes of direction, the general trend, however, being north-east and south-west. There are a number of islands at the upper end, all composed of masses of solid rock rising steeply from a great depth of water. The lake lies 476 feet above sea-level, and has a maximum depth of 205 feet, a mean depth of 83 feet, and the volume of water is estimated at 7870 million cubic feet.

Windermere, the largest lake in England, has an area of more than 5½ square miles, and its length measured along the curved axis, which trends north and south, is 10½ miles. The lake as a whole is surrounded by flatter shores and lower hills than most of the others, and its indentations are more numerous and varied. Its surface is the nearest to sea-level, being only 130 feet above it. A number of islands, all low and flat, occur about midway between the north and south ends, the largest of which is Belle Isle. The maximum depth, found at the northern end, is 219 feet, and the mean depth 78 feet. The lake is estimated to contain 12,250 million cubic feet of water, and it drains by the River Leven into Morecambe Bay.

The lakes of the Snowdon region and of that part of Carnarvonshire to the east of Snowdon were surveyed by Dr Jehu in 1900.[1] They are much smaller in area than the English lakes surveyed by Dr Mill, but some of them rival in depth even the largest of the latter, Wales.

[1] Jehu, "A Bathymetrical and Geological Study of the Lakes of Snowdonia and Eastern Carnarvonshire," *Trans. Roy. Soc. Edin.*, vol. xl. p. 419, 1902.

and their depth is far more striking when considered in proportion to their size. Yet in none of the Welsh lakes is the depth sufficiently great to bring any part of their bed below the level of the sea, as is the case in some of the English lakes; for while the latter, with the exception of Haweswater, lie at an elevation of less than 500 feet, the majority of the former are situated at a much higher level.

All the different stages in the existence of lakes are exemplified amongst those found in Carnarvonshire, and traces of old lakes, which have been gradually filled up by the sediment brought down by the inflowing streams and converted into flat meadows, are abundant in the district. Dr Jehu discusses the question of the origin of the Welsh lakes very fully, and comes to the conclusion that, while a few may be retained in whole or in part by morainic barriers, the majority probably lie in true rock-basins.

Llyn Glaslyn, 1971 feet above sea-level, the highest of the Snowdon lakes, is about a third of a mile long by one-sixth of a mile wide, has a maximum depth of 127 feet, and contains about 59 million cubic feet of water.

Llyn Llydaw, 1416 feet above sea-level, receives the overflow from Glaslyn, and is drained by Afon Glaslyn. It is rather more than a mile in length by about a quarter of a mile in breadth, has a maximum depth of 190 feet, and contains approximately 409 million cubic feet of water.

Llyn Cawlyd, 1165 feet above sea-level, the deepest of the lakes sounded by Dr Jehu, drains to the Conway. It is over a mile and a half long by about a quarter of a mile wide, has a maximum depth of 222 feet, a mean depth of about 110 feet, and contains about 941 million cubic feet of water.

Llyn Dulyn, which drains into the valley of the Conway by the Yr Afon Dulyn, is almost as deep as Llyn Llydaw, and is situated 1747 feet above sea-level. It is about one-third of a mile in length by one-quarter of a mile in breadth, has a maximum depth of 189 feet, and is estimated to contain about 156 million cubic feet of water.

Llyn Cwellyn is situated in a valley to the west of Snowdon, at the very moderate altitude of 464 feet above sea-level, and is drained by the River Gwyrfai. It is about 1¼ miles in length by about half a mile in breadth; the maximum depth is 122 feet, and the volume of water contained in the lake about 713 million cubic feet.

Llyn Padarn and **Llyn Peris,** two lakes about 340 feet above sea-level at the foot of the pass of Llanberis, appear at one time to have formed a continuous sheet of water, but are now separated by an alluvial flat made up of material brought down by tributary streams. The distance from the lower end of Llyn Padarn to the head of Llyn

Peris is over three miles, but the length of the original lake must have been much greater, for not only is there an alluvial expanse stretching above the head of Llyn Peris, but a marshy flat, partly under water and often flooded after heavy rains, extends a good way below the foot of Llyn Padarn. The maximum depth recorded in Llyn Padarn is 94 feet, and in Llyn Peris 114 feet. The outflow of the lakes is by the River Seiont to the Menai Straits.

Bala Lake, in Merionethshire, at the head of the river Dee, is larger than any of those surveyed by Dr Jehu, being about 3½ miles long by three quarters of a mile broad; and one still larger, **Lake Vyrnwyn,** an old lake artificially enlarged in order to increase the water-supply of Liverpool, was constructed about twenty years ago by building a dam, 1165 feet long, to hold back the head-waters of the Vyrnwyn River, a tributary of the Severn. This lake is capable of holding 2103 million cubic feet of water.

Many lakes of considerable extent exist both in the mountainous and lowland districts of Ireland, and the number of small lakes is very great. The total area covered by lakes amounts to 711 square miles. Careful surveys have been made by the Admiralty and maps published between the years 1835 and 1854 of the principal lakes, viz. Loughs Neagh, Mask, Corrib, Derg, Ree, and Erne (Upper and Lower), and also of the smaller Lough Derg in County Donegal. Ireland.

Lough Neagh, in the province of Ulster, the largest lake in the British Isles, receives the Upper Bann, the Blackwater, and numerous other streams, and discharges by the Lower Bann into the North Channel at Coleraine. It is 17 miles in length, about 10 miles in breadth, and covers an area of 153 square miles; it lies 48 feet above sea-level, and has a mean depth of 40 feet and a maximum depth of 102 feet. The islands are few and small, and the shores, particularly on the south, are flat and marshy. It lies in a volcanic area in a basin formed by fracture and subsidence. It is well stocked with fish—like trout, char, pullen.[1] Canals extend from Lough Neagh to Belfast, Newry, Tyrone, and Lough Erne.

Lough Mask, on the borders of Mayo and Galway, receives the waters of the River Robe, and the surplus waters of Lough Carra to the north-east of it and of Lough Nafooey to the west, and is drained by an underground stream into Lough Corrib. It is 35 square miles in area, 10 miles in length by 4 miles in breadth, with a maximum depth of 191 feet. Its elevation above sea-level is about 50 feet.

Lough Corrib, lying at an altitude of only 14 feet above sea-level, nearly divides County Galway into two parts. It is very irregular in shape, and contains many islets. It has a maximum depth of 152

[1] For analysis of the water of Lough Neagh, see p. 149.

feet, is 27 miles in length, from 1 to 6 miles in breadth, and covers an area of 68 square miles. In addition to the overflow from Loughs Carra and Mask, it receives also the rivers Beatanabrack, which enters at the head of the north-west arm, and Clare, which enters at the south-east end of the lough, and it discharges by Galway River into Galway Bay.

The country to the west of Lough Corrib contains about 130 lakes, 25 of which are more than a mile in length. These loughs may be divided into two divisions—bog-loughs and mountain-loughs. Those of the former class are irregular in outline, shallow, and studded with islands; the three largest, forming a chain at the base of the Twelve Pins, are Loughs Inagh, Derryclare, and Ballynahinch. Those of the latter class are deeper and smaller, only four exceeding a mile in length. In September 1904, three of the loughs of this district, viz. Dhulough, Glencullin, and Nafooey, were sounded by Mr O. J. R. Howarth.[1] **Dhulough**, one of the mountain type, is about 1¾ miles in length, and has a maximum depth of 164 feet. Its surface is 108 feet above sea-level, and a short stream carries its surplus waters to the estuary of the Erriff River. **Glencullin Lough**, to the north-west of Dhulough, 20 feet higher, and draining into it, is less than three-quarters of a mile long, and has a maximum depth of 27 feet; it is one of the bog type. **Lough Nafooey** is a mountain-lough, over 2½ miles in length by about half a mile in maximum breadth, situated nearly 94 feet above sea-level, and drained by the River Finny into Lough Mask. Howarth's deepest sounding is 148 feet.

Lough Derg, situated 108 feet above sea-level, on the borders of the counties of Galway, Clare, and Tipperary, and traversed by the River Shannon, has an area of 49 square miles. Like Lough Corrib, it is very irregular in outline, and contains many small islands. The maximum depth, obtained off Parker Point, is 119 feet.

There is another lake of the same name in the south of County Donegal, lying in the midst of a desolate mountain region, 457 feet above sea-level, and 6 miles long by 4 miles broad, flowing by the River Derg into the River Foyle and Lough Foyle. This lake was for centuries famous throughout Europe as a place of pilgrimage, and on Saints' Island, near the western shore, stand the ruins of an old monastery, destroyed in 1632.

Lough Ree, another lake in the course of the Shannon River, 122 feet above sea-level, between the counties of Roscommon, Longford, and West Meath, is 17 miles in length by 7 miles in maximum breadth, and has a maximum depth of 106 feet; it covers an area of approximately 60 square miles. Its shores are very much indented, and it contains a number of islands.

[1] *Geogr. Journ.*, vol. xxv. p. 172, 1905.

Lough Erne.—The River Erne issues from Lough Gowna on the borders of the counties of Longford and Cavan, and after passing through Lough Oughter merges into Upper and Lower Lough Erne, whence reissuing it flows into Donegal Bay at Ballyshannon. The united length of the two loughs and the connecting river is about 60 miles, the distance between the loughs being about 5 miles. The area of the Upper Lough is 15 square miles, and it has a maximum depth of 89 feet. It lies almost 2 feet above the Lower Lough, and is studded with islands to such an extent that there is scarcely any open water. The Lower Lough is about 149 feet above sea-level, has a maximum depth of 226 feet, and covers an area of 43 square miles.

Lakes of Killarney, three in number, all connected, and draining by the River Laune to Dingle Bay, are much frequented by tourists on account of the beauty of their surroundings. The largest, called Lower Lake or Lough Leane, has an area of not quite 8 square miles; the Middle or Muckross Lake, separated from the Lower Lake by a narrow peninsula, has an area of a little over 1 square mile; and the Upper Lake, 5 feet above the other two, and connected with them by a stream known as the Long Range, 2½ miles in length, has an area of only two-thirds of a square mile.

The lakes of Scandinavia are very numerous, occupying in Norway 4 per cent. of the surface, and in Sweden as much as 8 per cent.[1] Many long rivers, broken by picturesque waterfalls, and with numerous lakes in their courses, cross Sweden from west to east. Helland [2] cites the lakes of the northern portion as examples of true rock-basins excavated by ice action, but many are probably retained by drift barriers. Scandinavia.

Lake Hornafvan, the largest of these, is a narrow sheet of water, very irregular in outline and 70 miles in length. It lies at an elevation of 1394 feet above sea-level, and has an area of nearly 93 square miles. The maximum depth is 725 feet, the mean depth 253 feet, and the volume of water is estimated at 777,040 million cubic feet.[3] The outflow is by the Skelleftea River to the Gulf of Bothnia.

The depression of the great lakes lies to the south of the plateau of Southern Sweden, and contains four large bodies of water: Lakes Vener, Vetter, Hjelmar, and Mälar.

[1] The portion of the surface of Europe covered by lakes is 0·5 per cent. (see Yngvar Nielsen in Mill's *International Geography*, ed. 2, p. 199, London, 1907).

[2] "Die glaciale Bildung der Fjorde und Alpenseen in Norwegen," *Pogg. Annal.*, Bd. cxlvi. p. 538, 1872.

[3] The measurements given for the European lakes (except length and breadth) are taken mostly from Halbfass, "Die Morphometrie der europäischen Seen," *Zeitschr. Ges. Erdkunde Berlin*, Jahrg. 1903, pp. 592, 706, 784.

Lake Vener, the third largest lake in Europe, with a length of 112 miles, a breadth of 56 miles, and an area of 2149 square miles, is situated towards the west of the depression, and drains to the Kattegat through the Göta; the Klar, the greatest Scandinavian river, flows into the lake. Lake Vener lies at an elevation of 144 feet above sea-level; the maximum depth is 292 feet, the mean depth 108 feet, and the volume of water contained in the lake is estimated at about 6,357,600 million cubic feet. It is connected with Lake Vetter by canal.

Lake Vetter lies at an elevation of 289 feet above sea-level, has a length of 80 miles, an average width of about 18 miles, and has an area of 733 square miles. The maximum depth is 413 feet, the mean depth 128 feet, and it is estimated to contain about 2,543,000 million cubic feet of water. It receives short streams from the plateau of Southern Sweden, and discharges eastwards by the large Motala River to the Baltic. By the eastern branch of the Göta Canal it has navigable communication with Lake Vener.

Lake Mälar also drains to the Baltic. It lies at an elevation of only $1\frac{1}{2}$ feet above sea-level, and covers an area of 450 square miles. The maximum depth is 210 feet, the mean depth 26 feet, and the volume is estimated at about 353,200 million cubic feet.

Lake Hjelmar lies about 70 feet above sea-level, and covers an area of 185 square miles. The greatest depth is 65 feet, and the outflow of the lake is to the Baltic.

Reference may here be made to the remarkable temperature conditions recorded in a small lake in the island of Tysnös, off the coast of Norway, the depth of which does not exceed 15 feet.[1] When visited in 1888 the temperature at the surface was 54°·7 F. (12°·6 C.), but at one foot below the surface it rose to 60° F. (15°·56 C.), at four feet down it was 69°·2 F. (20°·67 C.), at seven feet down it was 73°·0 F. (22°·78 C.), the maximum temperature of 74°·0 F. (23°·33 C.) being reached at ten feet below the surface; further down the temperature fell distinctly, being only 72°·0 F. (22°·22 C.) at the bottom. On 30th June 1888 the maximum temperature was no less than 81°·3 F. (27°·4 C.) at about seven feet beneath the surface, and fell to 78°·8 F. (26°·0 C.) by July 21, being then between nine and ten feet below the surface, and to 73°·9 F. (23°·28 C.) by 11th August at about eleven feet beneath the surface. Careful search had been made for a hot spring, but nothing of the kind could be found, and the conclusion was that these phenomenal temperatures were due to solar radiation; this is supported by the fact that the specific gravity *in situ* of the intermediate and hottest layer lies between that of the surface and bottom

[1] See Gibson, *Seventh Annual Report of the Fishery Board for Scotland*, Part III. p. 433, 1889.

layers, which must tend to prevent convection currents and therefore to greatly prolong the cooling of the intermediate layer. Salt water is admitted intermittently from the neighbouring fjord, and forms the bottom layer, the thin surface layer being formed by fresh water from a small stream flowing in at one end and overflowing at the other, and being thus constantly renewed; the intermediate layer is apparently formed by very slow mixing of the bottom and surface layers. This little lake was used as an oyster nursery with great success, the high temperature developing the spat with remarkable rapidity, and with a degree of regularity from year to year surpassing anything attained in the fjord waters outside (see p. 587).

Northern Russia.

That portion of Russia formerly covered by the ice-sheet is known as the Lake Region, and includes Finland and the Russian governments of Olonets, Novgorod, St Petersburg, and Pskov. So numerous are the lakes in this part that they form a labyrinth of sheets of water and marshes, communicating with each other by rivers interrupted by rapids, the land not covered by water consisting of isthmuses and peninsulas. The government of Novgorod alone contains 3200 separate lakes, and that of Olonets 2000. The Russian portion of the Lake Region includes 15,500 square miles of water-surface.

Lake Enare.—The large lake Enare, in Russian Lapland, has an area of about 550 square miles, and drains through the Pasvigelf into the Varanger Fjord. Its elevation is 394 feet above sea-level, and the maximum depth is 30 feet.

Of the total area of the rocky table-land of Finland, one-tenth is covered by water.

Lake Saima.—The largest lake in Finland is Lake Saima, with an area of 680 square miles. It lies at an altitude of 256 feet, and has a maximum depth of 187 feet. It is connected by the Saima Canal with the Gulf of Finland, and drains by the Vuokosen, which forms the Imatra Rapids—the grandest rapids in Europe,—to Lake Ladoga.

River Neva.

The River Neva (see fig. 70) flows into the Gulf of Finland, and carries off the drainage of the two largest lakes in Europe, Lakes Ladoga and Onega.

Lake Ladoga is the largest sheet of fresh water in Europe; it is three times the size of Lake Vener, and thirty times that of the Lake of Geneva. Its length is 128 miles, its maximum breadth about 80 miles, and its area, including the islands, is 7015 square miles. Its maximum depth is 732 feet, its mean depth 300 feet, and it is estimated to contain 43,228,000 million cubic feet of water. In former times it formed one basin with the Gulf of

Finland; to-day it is 16 feet above sea-level. Schokalsky[1] made temperature observations in the summers of 1897 and 1899, and reported that in 1897 the vertical distribution of temperature was

Fig. 70.—River Neva drainage basin.

direct throughout, though a great difference was observable between the figures obtained in the north and south portions of the lake, the water of the northern deeper part being colder both at the surface and at fixed depths than in the southern part. The warmest surface

[1] See "Le Lac de Ladoga au point de vue thermique," *VII. Internat. Geogr. Kongr.*, p. 263, Berlin, 1899.

water (in the south) had a temperature of 55°·6 Fahr. (13°·1 C.), and the coldest bottom water (in the north) was 39° Fahr. (3°·9 C.). These temperatures seemed relatively low for the time of year, but still lower figures were recorded in 1899, especially in the north. In the latter year the vertical distribution of temperature was found to be inverse at all the deep-water stations, the difference from the distribution in 1897 being attributable to the unusually low temperature which had prevailed throughout North-Western Russia during the spring and early summer of 1899. Although Ladoga certainly belongs to the category of temperate lakes, according to Forel's classification, it would appear to come very near the border-line separating temperate from polar lakes, in which the vertical distribution is always inverse. The maximum temperature gradient occurred at a much lower level in 1899 than in 1897, because of the generally higher temperature of the water in 1897. The lake is covered with a sheet of ice annually from December till April, and near Valaam Island masses of ice are sometimes piled up to a height of 75 feet, presenting from a distance the appearance of hills of weathered schist. Notwithstanding the freezing of the lake, its animal life is very abundant, including not only fishes but a species of seal, which may be seen in winter at the edge of the ice-cracks.

Lake Onega lies 236 feet above sea-level, and has an area of 3763 square miles. The length of the lake is 145 miles, the greatest depth 740 feet,[1] and the volume of water is estimated at 21,000,000 million cubic feet. The River Svir connects it with Lake Ladoga, and a series of lakes and rivers affords communication with the White Sea. Its northern shores form numerous bays running to the north-west, and the water-system is prolonged towards Lapland by chains of small lakes and rivers following the same direction, separated by lines of hills between 800 and 1000 feet high. The River Vitegra brings it into connection with the Volga system on one side and with the Mezen on the other.

Three small lakes[2] lying to the south of Lake Onega, and communicating with that lake by the Megra River, belong to the class of intermittent lakes, and are connected with the "Karst"[3]

[1] Halbfass gives the maximum depth as 124 metres (407 feet), and the altitude as 174 metres (571 feet).

[2] See *Geogr. Journ.*, vol. xxxi. p. 441, 1908.

[3] In Austria-Hungary a region along the east side of the Adriatic Sea, known as the Karst, is a tract of land underlain by white limestone nearly free from soil. Atmospheric agencies have eroded its surface so that sink-holes abound, and numerous short gullies, ravines, and valleys in the limestone terminate abruptly, discharging their waters into caves or subterranean tunnels, from which the streams may not emerge till they reach the coast. Topography similar to that of this region, and developed in the same way, is known as Karst topography.

topography of the limestone region south of Lake Onega. These lakes are connected by natural channels, but as the basins are not filled and emptied simultaneously, the direction of flow in the channels changes from time to time. The largest of the lakes, Shimozero, discharges its waters into an underground abyss some 14 miles to the east, and is sometimes completely empty by November. The Dolgozero, at the other end of the system, is drained in a similar manner. These lakes and others in the vicinity, differ from the Lake of Zirknitz[1] (the classical example of an intermittent lake) in not being filled again by the same channel by which they are emptied, but by ordinary above-ground agencies, the process sometimes taking as long as seven years.

Lake Ilmen, which also belongs to the Neva system, is really nothing more than a permanent inundation formed by a large number of rivers which meet at a point whence the outlet is not large enough to carry off the whole of the water. The lake lies at an altitude of 107 feet, and has an area of 358 square miles, being 30 miles in length from east to west by 24 miles in maximum width, but the depth does not exceed 30 feet. Its waters are generally muddy, as are also those of the River Volkov, its outflow, which is the chief affluent of Lake Ladoga. The principal streams meeting in Lake Ilmen are the Shelon, the Lovat, and the Msta, which brings it into communication with the Volga.

River Narova.

Lake Peipus (or Chudskoye) is a triple lake, the northern part of which is Lake Peipus proper, the southern Lake Pskov, and the connecting channel, 40 miles long by 3 to 10 miles wide, Lake Teploye. The area of the whole lake to the end of Lake Pskov is 1356 square miles,[2] and the area of the northern portion (Lake Peipus proper) is 1082 square miles. The maximum depth, which was found in Lake Teploye, is 90 feet, and the altitude is 97 feet above sea-level. It receives the Rivers Velikaya and Embakh, and its outlet is by the Narova to the Gulf of Finland. The area of Lake Peipus has been considerably increased in consequence of the drainage of the surrounding country having been conveyed into it more abundantly, through the construction of 1200 miles of artificial cuttings.

[1] Lake Zirknitz is situated in the Karst region in Austria. For a number of seasons together the bed of the lake may remain quite dry and be used for cultivation, while at other times it is occupied by waters teeming with fish. The underground outlets for the superficial water are sometimes comparatively empty, sometimes overflowing. In the former case the fissures communicating with these periodical lakes serve as channels to lead away the water; in the latter they serve as vents to pour the water on the plain.

[2] Helmersen, cited by K. Peucker, "Europäische Seen nach Meereshöhe, Grösse und Tiefe," *Geogr. Zeitschr.*, Bd. ii. p. 612, Leipzig, 1896.

Only two lakes of any importance are associated with the River Danube, viz. Lakes Balaton and Fertö in Hungary, on the right bank of the river. River Danube.

Lake Balaton (or Platten See) is about 50 miles in length, by 5 miles in average breadth, and has an area of about 250 square miles, oscillating with the rainfall. According to Halbfass, the maximum depth is 36 feet, but its average depth is only 10 feet, and therefore the volume of water contained in it is relatively very small, viz. 69,700 million cubic feet. It lies 344 feet above sea-level, and in some places on the south its shores are low and swampy, so that it has frequently been proposed to drain it, and an attempt has been made to reclaim its banks to some extent for cultivation. In consequence of its slight depth, the annual range of temperature in the lake is very great, the extreme being from 32° to about 82° Fahr. (0° to 27°·8 C.). The water temperature follows the air temperature fairly closely, and sudden great changes in the latter, whether due to wind or the fall of rain, snow, etc., are immediately reflected in the former. The very marked narrowing of the lake at the peninsula of Tihany divides it into two separate basins, and uninodal seiches of each have been observed. The principal seiche of the whole loch is the uninodal, and the depth being very slight relatively to the length, the period of this is very great—from ten to twelve hours—but the amplitude is relatively small compared with other great lakes. According to Cholnoky,[1] mirages are produced when the lowest strata of air are warmer than the upper, a condition fulfilled on the Balaton Lake chiefly in late autumn, when mirages are of almost daily occurrence and are observed in the morning. In these mirages, objects appear to be lifted up and to float in the air above the surface of the lake; the images are duplicated by the reflection below. Its waters are slightly brackish, in consequence of the efflorescences of salt formed on the Tertiary strata in the neighbourhood of the lake, and also on account of evaporation being at times greater than precipitation: twice in the last fifty years, for a period of many months the lake has had no outflow. The outlet of the lake to the Danube is by the Sio and Sarviz Rivers. The longer axis of the lake is parallel to a line of local volcanic action, and Judd[2] concludes that it is a depression due to the settling down of surface rocks into a cavity emptied by the ejection of lava. On account of the shallowness of the lake, there is no pure plankton, the organisms which constitute the plankton in deeper lakes, though present, being mingled with

[1] *Resultate der wissenschaftlichen Erforschung des Plattensees*, herausgegeben von der Plattensee Commission der Ung. Geogr. Gesellsch., Wien, 1897–1906.

[2] *Geol. Mag.*, vol. iii. p. 6, 1876.

numerous littoral and bottom forms. More than one thousand species of plants and animals are noted, the numbers being approximately equal.

Lake Fertö (or Neusiedler See), in the extreme west of Hungary, 370 feet above sea-level, is so extremely shallow (maximum depth 13 feet, mean depth not averaging 3 feet) that it sometimes evaporates completely in very dry years, as it did in 1865. It is refilled by the waters of the Danube when the river rises sufficiently high to force back the sluggish stream of the Hanság, which communicates with Lake Fertö through the Hanság swamp on the east, now for the most part under cultivation. The lake is 18 miles in length, by from 4 to 7 miles in breadth, and sometimes attains an area of 130 square miles.

Lake St Moritz, etc.—The River Inn, a tributary of the Danube rising in Switzerland, has a chain of lakes near its source, viz. Lake St Moritz, Lake Campfer, Lake Silva Plana, and Lake Sils, which have been referred to as typical illustrations of the lakes sometimes associated with river capture. The upper portion of the Engadine, the valley of the Inn, is of such a breadth as would appear to indicate a great river, the source of which must be miles away.[1] Instead of this there flows through the valley a small stream with a succession of lakes threaded on it. At Maloja the valley itself, still broad and deep, suddenly ends with a steep descent into the Val Bregaglia, through which the River Maira flows. The slope of the Val Bregaglia being much steeper than that of the Inn, the River Maira gradually cut its way back, and appropriated more and more of the territory which once belonged to the Inn. The Val Marozzo, now called the Upper Maira, and the Val Albigna were once tributaries of the original Upper Inn, but have been carried off into Italy by the victorious Maira. Hence the Upper Engadine is from the first a broad valley, because it represents part of the course of a stream which has lost its head-waters. Before this change the flow of water down the main valley was sufficient to carry off the materials brought down by the lateral tributaries, but, since the head-waters have been cut off and carried away into Italy, this is no longer the case; hence the lateral streams have built up dams across the valley, thus creating a chain of lakes. Johnson,[1] on the other hand, says there is reason to believe that the lakes occupy basins of glacial origin. The three lakes Campfer, Silva Plana, and Sils formerly constituted a single body of water which was ultimately divided by the growth of deltas deposited by side streams, and Lake Sils is at

[1] Lubbock, *Scenery of Switzerland*, p. 453, London, 1896.

[2] D. W. Johnson, "Hanging Valleys," *Bull. Amer. Geogr. Soc.*, vol. xli. p. 665, 1909.

present in process of being divided into two parts in the same way. The tributary streams enter the main valley of the Inn at points well up on the valley sides, and their waters fall abruptly in cascades to the main stream below. Such "hanging" valleys are of common occurrence in Switzerland, and are regarded as a reliable indication of glacial erosion in the main valley.[1]

In Transylvania many small lakes owe their salinity to the presence of rock-salt in the district, and may contain as much as 25 per cent. of common salt. In the Medve Lake,[2] the largest of the group near Szováta, the area of which is 0·01 square mile, with a maximum depth of 34 metres (112 feet) and an average depth of 10 metres (33 feet), observations on the temperature gave the following results. At the surface, where there is a superficial layer of fresh water, the temperature varies with that of the atmosphere, and in summer is 68° to 86° Fahr. (20° to 30° C.); below the surface the temperature rises gradually, and at a depth of 1·32 metres (4¼ feet) reaches its maximum of 133° Fahr. (56° C.). Below this it again falls, and is 86° Fahr. (30° C.) at a depth of 5·32 metres (17½ feet). The conversion of the solar rays into heat in the salt layer depends on the fresh-water layer on the surface.[3] This phenomenon also occurs in other Hungarian salt lakes, as well as in Wallachia and elsewhere, and in the lagoons found on parts of the shore in Norway (see p. 580).

Scutari Lake (or Skader), situated half in Montenegro and half in Albania, at an elevation of 20 feet above sea-level, drains into the Adriatic by the River Bojana, which enters the sea at the boundary- River Bojana.

[1] Davis, "Glacial Erosion in France, Switzerland, and Norway," *Proc. Boston Soc. Nat. Hist.*, vol. xxix. p. 273, 1901; Davis reviews the previous writings on hanging valleys on pp. 311 *et seq.*

[2] See *Scot. Geogr. Mag.*, vol. xviii. p. 317, 1902; vol. xx. p. 216, 1904.

[3] In this connection Professor Kaleczinsky (see "Ueber die ungarischen warmen und heissen Kochsalzseen als natürliche Wärme-Accumulatoren, sowie über die Herstellung von warmen Salzseen und Wärme-Accumulatoren," *Földtani Közlöny*, Bd. xxxi. p. 1 (sep.), 1902; "Ueber die Akkumulation der Sonnenwärme in verschiedenen Flüssigkeiten," *Math. u. naturw. Berichte aus Ungarn*, Bd. xxi. p. 1 (sep.), 1904) conducted a series of observations on tubs sunk in the ground and filled with various saline solutions, each tub bearing a superficial layer of fresh water, while a tub of fresh water served as a control. In the latter it was found that the warmest layer of water was the superficial one, which never reached a higher temperature than 86° F. (30° C.). In all the other cases the conditions were the same as in the salt lakes, *i.e.* the highest temperature was never observed at the surface, but in the lower layers. Kaleczinsky believes that similar conditions prevailed in geological times, and that the layers of salt obtained in salt-mines form as it were a kind of geological thermometer. Thus he believes that the rings of anhydrite well known in salt-mines have been deposited in summer when the temperature of the water was high, while the deposits of rock-salt took place in winter when the temperature of the water was low.

line between Montenegro and Turkey. The principal affluent is the Montenegrin river Moratcha, which enters the lake at the north-western end. The lake is 25 miles long by 5 or 6 miles wide, and covers an area of 137 square miles. Close to the steep south-western margin are over a dozen deep holes, the maximum depth of 144 feet being found in one of these situated near the village of Radus. The mean depth is 16 feet, and the volume of water contained in the lake is estimated at about 60,000 million cubic feet.[1] Recently a portion of the stream of the Drin, which is formed by the junction of the Black Drin and the White Drin and flows out into the Adriatic not far south of the Bojana, has found its way into the Bojana channel; the result has been a rise in the level of Lake Scutari and the inundation of the adjacent lowlands.

Lake Ochrida (or Okhrida), which occupies one of the plateaus of Eastern Albania, lies at an elevation of 2253 feet above sea-level, and is the chief source of the Drin. It is about 18 miles in length, from 4 to 7½ miles in breadth, and covers an area of 105 square miles. The maximum depth is 942 feet, the mean depth 479 feet, and the volume of water is estimated at 1,391,000 million cubic feet.[2]

River Po. The River Po and its tributaries drain the plain of Lombardy, a valley of subsidence at the base of the great arch of the Alps (see fig. 71). For ages the river has been occupied in filling up this great depression, and at Milan a boring was sunk 530 feet without reaching the bottom of the river deposits.[3] Such an accumulation would have required a longer period of time had not the river been assisted in its work by the large masses of loose debris which lie at the lower end of each great valley opening on the plain of Lombardy, and from which stones, sand, and mud are washed down in time of flood, and scattered across the plains by the Po and its affluents. These masses represent the moraines shed from the ancient glaciers that filled the Alpine valleys to the brim in the glacial period and fed the waters of the Po. A remarkable phenomenon, that has led to much discussion, is that, while there are lakes in some of these valleys at the present day, in others there are none, and it is difficult to understand how eroded detritus could have been carried along the former type of valley and yet have left it, as in the case of that occupied by Lake Maggiore, 2000 feet below the level to which the plain beyond has been filled. Lyell[4] suggested that the valley of the Ticino, in which Maggiore lies, had been so elevated and depressed

[1] See Halbfass, *op. cit.*, p. 206. [2] *Ibid.*

[3] Penck, cited by Lubbock, *op. cit.*, p. 137.

[4] See Ramsay, "Sir Charles Lyell and the Glacial Theory of Lake Basins," *Phil. Mag.*, vol. xxix. p. 285, 1865.

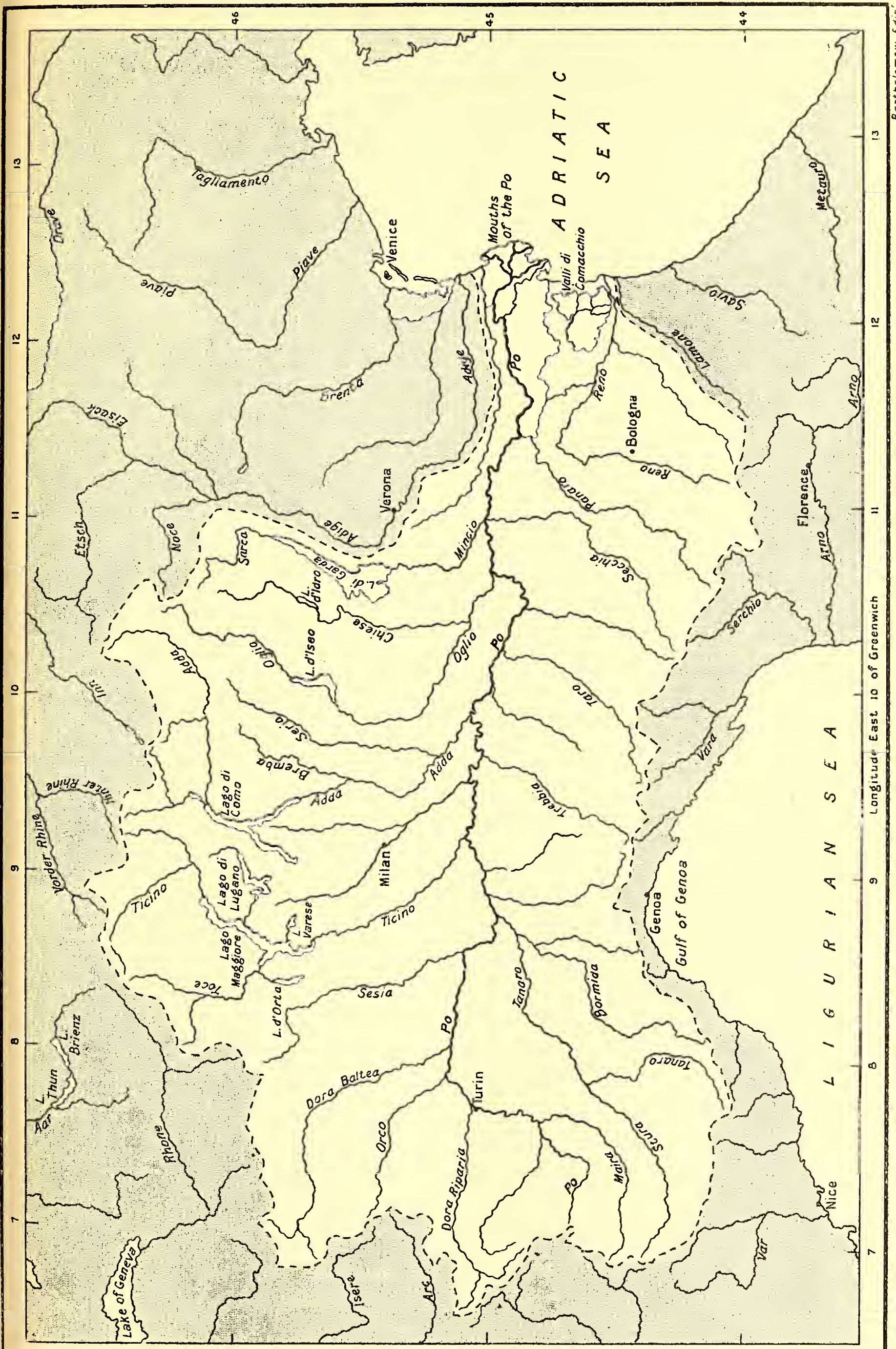

FIG. 71.—River Po drainage basin.

by transverse folding as to interrupt the continuous slope of its water-line, with the result that the depression filled up and formed a lake. To this explanation, however, Ramsay made objection, and suggested a glacial origin as agreeing with the fact that all these lakes on the Italian slope of the Alps opening into the plain of the Po have strong moraines at their southern margins. Davis[1] at first admitted that both of these causes might be concerned, and considered that their relative importance could not be estimated. In a later paper,[2] however, he stated he had come upon certain phenomena in the Alps and in Norway that demanded wholesale glacial erosion for their explanation. An examination of the district about the Lake of Lugano had not led to the discovery of any effects of warping and tilting, such as must of necessity be present if Lyell's theory of the origin of the lakes be the correct one. On the other hand, the evidence of strong glacial erosion was very marked.

Beginning at the west and taking these valleys in order, we have the Dora Baltea, which led a vast glacier down from Mont Blanc to the great moraines of Ivrea (from 1000 to 2000 feet in height), and yet is lakeless excepting for several small basins caught in the moraines; the Sesia, which is lakeless; the Toce with the Lake of Orta; the Ticino with Lake Maggiore and several small lakes, Comabbio, Varese, etc., between the morainal deposits; the small valley of the Agno and Cassorate, of less size than many lakeless valleys, and yet occupied by the Lake of Lugano; the Adda with the Lake of Como in its branching course, and Annone, Pusiano, and other lakes in its terminal moraine; the Bremba and Serio, both lakeless; the Oglio with the Lake of Iseo and well-marked moraines; the Chiese with the Lake of Idro; the Sarca with the Lake of Garda, the largest of all and projecting farthest into the plain, with a great lobed moraine to enclose it.

Lake of Orta lies 951 feet above sea-level, is 8 miles long by about 5 miles in maximum breadth, and has an area of about 7 square miles. A subaqueous ridge divides it into two basins, of which the northern one is the deeper, attaining a maximum depth of 469 feet, the mean depth being 233 feet; the volume of water is estimated at 45,669 million cubic feet. The temperature of the bottom water never falls below 39°·2 Fahr. It differs from the other Italian lakes in having its outflow not in the natural line of the drainage, viz. to the south, but to the north. This is due to the southern end being closed by a moraine.

Lake Maggiore lies 636 feet above sea-level, and covers an area

[1] "Classification of Lake Basins," *Proc. Boston Soc. Nat. Hist.*, vol. xxi. p. 358, 1883.

[2] "Glacial Erosion in France, Switzerland, and Norway," *Proc. Boston Soc. Nat. Hist.*, vol. xxix. p. 273, 1901.

of 82 square miles. The maximum depth is about 1220 feet, the mean depth 574 feet, and it is estimated to contain about 1,310,000 million cubic feet of water.

Lake of Varese lies 778 feet above sea-level, and covers an area of 6 square miles. The maximum depth is 85 feet, the mean depth 36 feet, and it is estimated to contain about 5722 million cubic feet of water.

Lake of Lugano lies at an elevation of about 889 feet above sea-level, and covers an area of 19 square miles. It has a maximum depth of 945 feet, a mean depth of 427 feet, and is estimated to contain about 231,699 million cubic feet of water.

Lake of Como lies at an elevation of about 653 feet above sea-level, the variation in the water-level amounting to as much as 16 feet, and covers an area of 56 square miles. It has a maximum depth of 1345 feet, a mean depth of 513 feet, and is estimated to contain about 794,700 million cubic feet of water. A bottom temperature of 42°·8 Fahr. has been recorded.

Lake of Iseo lies 610 feet above sea-level, and covers an area of 23 square miles. The maximum depth is 823 feet, the mean depth 403 feet, and it is estimated to contain about 268,000 million cubic feet of water.

Lake of Garda lies 213 feet above sea-level, and covers an area of 143 square miles. The maximum depth is 1124 feet, the mean depth 446 feet, and it is estimated to contain about 1,766,000 million cubic feet of water.

Rivers Rhine and Rhone.

The great rivers, the Rhine and the Rhone, have their origin in Switzerland, and the only important lakes drained by these rivers or their tributaries occur in that country (see fig. 72). The explanation of this fact lies in the changes which Switzerland has undergone. The Swiss rivers are of very different ages, some being of comparatively recent origin, while others date back to very great antiquity, and parts of what is now considered a single river differ in age and history. The whole drainage of Switzerland north of the Alps originally found its way by the Danube to the Black Sea, and only after the subsidence which separated the Vosges and the Black Forest did the waters of the Rhine flow northward. After that the waters of the Rhone still joined the Rhine, and ran over the plains of Germany to the North Sea, till finally the Rhone broke its way by Fort de l'Ecluse, and falling into the Saône flowed to the Mediterranean. Another general change in the river-system is due to the fact that the watershed has retreated northward, because, the southern slope being much steeper than the northern slope, the Italian rivers have the greater power of erosion, and are gradually eating their way back. The way in which

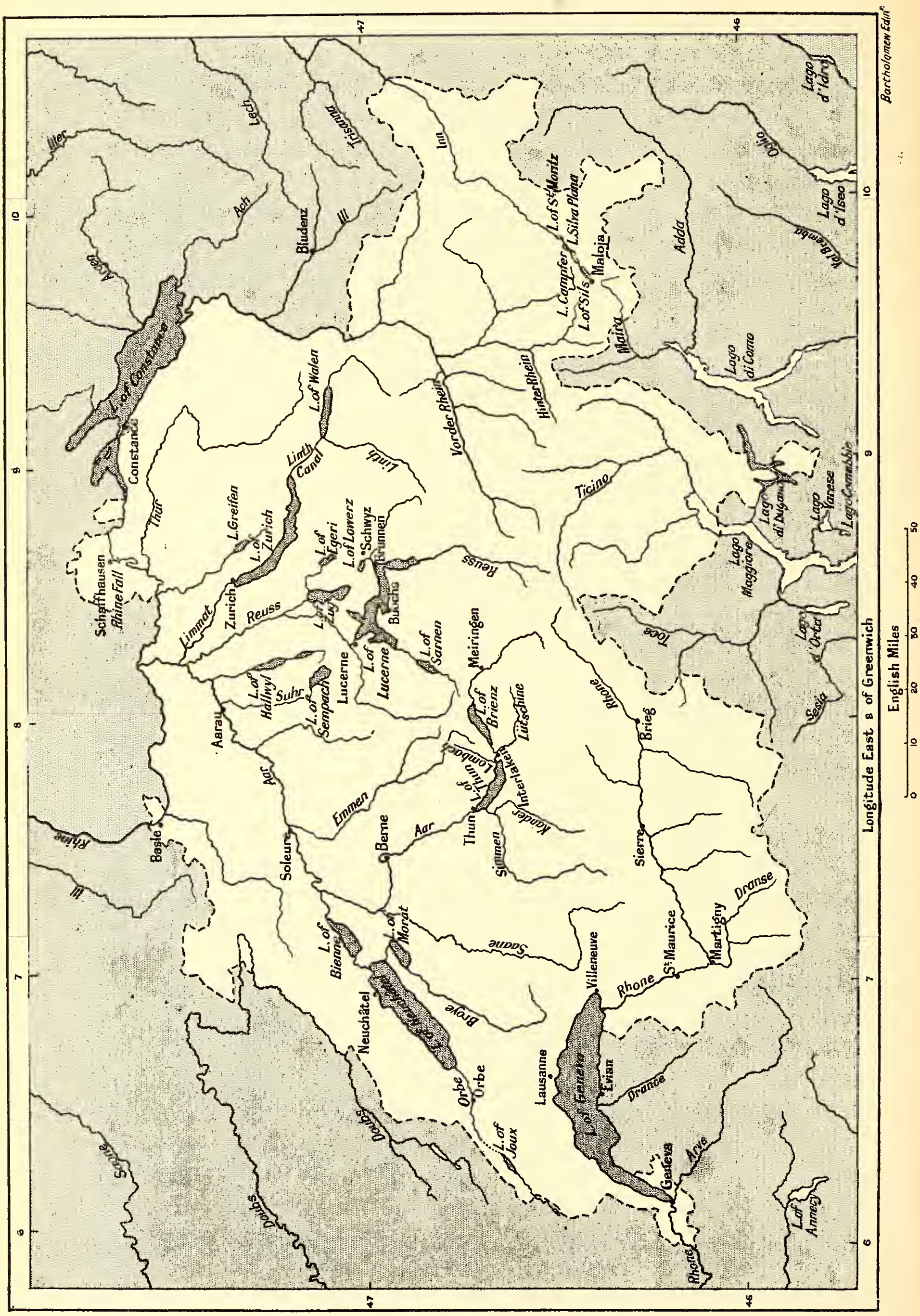

FIG. 72.—Switzerland.
[The Swiss Lakes are darkly stippled.]

this has led to the formation of lakes in the Upper Engadine has been already explained. In addition to these alterations in the river-system, recent changes of level are said to have diverted the courses of some of the rivers, and to have drowned parts of their valleys. The dams due to river-cones and glacial moraines have had the same effect. In general, the rivers follow the original folds of the strata, or cut across them at right angles, and in the latter case it is most probable that the river is older than the folds, and cut through them as they rose. Lakes may have existed there for a time, but as the ridges were cut down the lakes were then drained. The valley of the Rhine above Martigny, and the valley of the Rhone above Chur, mark the sites of such temporary lakes.

According to Heim,[1] the Alps were formerly higher than they are at present, and the rivers cut out wide valleys at that time. Later, the Alps sunk as a whole from 200 to 500 metres (650 to 1640 feet), and by this sinking part of the valleys were drowned and lakes were formed. Proof of this sinking is found in the old terraces of many of the rivers, which run in the opposite direction to the present course of the rivers, in the filling up of the principal valleys with gravel, and in a bending in the Molasse which can be followed along the whole northern border. This view is supported by Aeppli and by Römer, and also by recent researches made in the Alpine border lakes by Dr E. Gogarten. On the other hand, Penck and Brückner[2] hold the theory that these lakes can be explained by glacial erosion, and that there is no evidence of subsidence.

The Upper Rhine is generally stated to have its source in the small lakes, Siarra and Toma.

Lake of Constance (or Bodensee) is the first large lake in its course, and lies at an elevation of about 1300 feet above sea-level. It has an area of 208 square miles, and is 40 miles in length; the maximum depth is 827 feet, and the mean depth 295 feet. The volume of water is estimated at 1,711,000 million cubic feet. At its west end it is dammed up to a certain height by the deposits of the ancient Rhine glacier, but this would not account for more than, say, a quarter of its depth. Penck[3] considers it a rock-basin due to changes in relative levels or to excavation by the glacier.

Below the Lake of Constance the course of the Rhine gives indications of being comparatively recent, and is interrupted by bars of rock, one of these bars causing the magnificent fall of Schaffhausen and regulating the height of the Lake of Constance, which

[1] Albert Heim, "Geologische Nachlese," No. 1, "Die Entstehung der alpinen Rand-Seen," *Vierteljahrsschr. naturforsch. Ges. Zürich*, vol. xxxix. p. 1 (sep.), 1894.

[2] *Die Alpen im Eiszeitalter*, vol. ii. p. 537, Leipzig, 1909.

[3] Cited by Lubbock, *op. cit.*, p. 414.

would have been much lower if the Rhine had been running in its former bed.

The course of the Aar, which joins the Rhine on the left bank between Schaffhausen and Basle, is interrupted by rapids caused by the uplift of ridges across the course of the river. Below Innertkirchen is a ridge of rock, above which it has been supposed the river once formed a lake in the depression known as "Hasli-im-Grund." There is no direct evidence of this, however, and the river may have formed the famous Aar gorge by cutting through the ridge as it rose. Below Meiringen the river flows through a broad, flat valley, with terraces on each side, which was evidently once much deeper, and formed part of the Lake of Brienz, but has gradually been filled up by the river.

Lake of Brienz is 9 miles in length, by 2 miles in maximum breadth, and covers an area of 11 square miles. It lies 1857 feet above sea-level, has a maximum depth of 856 feet, a mean depth of 577 feet, and is estimated to contain about 182,600 million cubic feet of water. The Lakes of Brienz and Thun were originally one, the level plain upon which Interlaken stands having been formed by the deposits of the River Lütschine, coming from Grindelwald on the south, and of the River Lombach, draining the valley of Habkern on the north. To judge from the depth of the lake, these deposits must be at least 1000 feet in thickness.[1]

The Aar follows a winding course on the plain of Interlaken, being first directed to the right by the cone of the Lütschine, and then to the left by that of the Lombach. The lower end of the Lake of Thun is dammed up in part by the deposits of the Simmen and the Kander, but the lower end of the valley has risen relatively.

Lake of Thun lies 1837 feet above sea-level, and covers an area of about 18 square miles. The greatest depth is 712 feet, and the mean depth 443 feet. The volume of water contained in it is estimated at about 229,600 million cubic feet.

The Thièle (Zihl) rises under the *névé* of Orbe in the valley of the Joux, in the Jura, and after flowing for some miles in an underground channel passes through the Lakes of Neuchatel and Bienne to join the Aar. The Jura range consists mainly of calcareous strata, often much fissured, so that the rain sinks into the ground and reappears after a longer or shorter course underground. Thus the River Orbe commences in a closed valley. The upper part, or Vallée de Joux, is double, one branch being without any river, except a little streamlet which flows into the Lake of Ter. The southern valley is traversed by the Upper Orbe, which falls into the Lake of Joux, and its continuation, the Lake of Brenet. Neither of these lakes has any

[1] Lubbock, *op. cit.*, p. 382.

open outlet, but the waters escape by an underground passage and reappear above Vallorbes, whence they flow to the Lake of Neuchatel.

Lakes of Joux and Brenet together cover an area of 3½ square miles, and lie at an elevation of 3307 feet above sea-level. The maximum depth is 112 feet, and the mean depth 59 feet.

Many small lakes in the Jura Mountains occupy troughs formed by downfolded strata, and the Lake of Joux is marked at its north-east end by a strong cross fault.[1]

Lake of Neuchatel (or Neuenburger See) lies at an elevation of 1417 feet above sea-level, and covers an area of about 85 square miles. Its greatest depth is 505 feet, its mean depth 210 feet, and it is estimated to contain about 500,500 million cubic feet of water. It occupies a synclinal valley, as do also the Lakes of Brenet and Morat. It is surrounded by marshes, which used to cover about 50,000 acres, but a good deal of that area has now been drained. At one time the Lake of Neuchatel formed a single sheet of water with the Lake of Bienne, and extended from Orbe on the west to Soleure on the east. Guyot considers the Lake of Neuchatel the result of local depression.[2]

Lake of Bienne (or Bieler See) lies at an elevation of 1417 feet above sea-level, and covers an area of 17 square miles. It has a maximum depth of 249 feet, a mean depth of 92 feet, and its volume is estimated at about 43,800 million cubic feet.

Lake of Morat (or Murten See) lies about 1427 feet above sea-level, and covers an area of 10½ square miles. Its maximum depth is 157 feet, its mean depth 72 feet, and it is estimated to contain about 21,200 million cubic feet of water. It drains into the Lake of Neuchatel by the River Broye.

The River Suhr drains the Lake of Sempach, and joins the Aar below Aarau. The valley it occupies is out of all proportion to the size of the present river, which has excavated its channel entirely in glacial deposits. Hence this valley and others of a similar description are attributed by Kaufmann[3] and Gremaud[4] entirely to glacial action. The glacier which came down the valley of the Suhr is supposed by Kaufmann to have been obstructed by the hill of Wohlen, and the pressure of the ice caused by this obstacle may account for the depression now occupied by the Lake of Sempach, which is dammed by the moraine.

Lake of Sempach lies about 1663 feet above sea-level, and covers an area of 5½ square miles. It has a maximum depth of 285 feet,

[1] See Sheet XI., Swiss Geol. Commission.

[2] *Mém. Soc. Sci. Nat. Neuchâtel*, t. iii., No. 6, 1845.

[3] *Beitr. z. geol. K. d. Schw.*, xi., 1872.

[4] Gremaud, "Quelques données sur les vallées primitives et les vallées d'érosion dans le canton de Fribourg," *Bull. Soc. Fribourgeoise Sci. Nat.*, Ann. v.–viii. p. 25, 1888.

a mean depth of 151 feet, and the volume of water contained in it is estimated at about 22,380 million cubic feet.

The River Reuss joins the Aar not far from its junction with the Rhine, and drains the Lake of Lucerne.

Lake of Lucerne (or Vierwaldstätter See, or Lac de Quatre Cantons) lies 1433 feet above sea-level, is 44 square miles in area, has a maximum depth of 702 feet, and a mean depth of 341 feet. It is estimated to contain 417,447 million cubic feet of water. From an ancient delta of the Muotta, and remains of terraces, it would appear, says Du Pasquier,[1] that the water once stood nearly 100 feet above its present level. It would then have been continuous with the Lake of Zug. Heim regards the lake as a complication of several river valleys which were "drowned" at the same time. It belongs to what he terms "Rand-Seen," *i.e.* lakes situated on the north and south borders of the Alps, such as the Lake of Geneva, Zürich, etc., caused by a subsidence of the Alps. The old river-terraces of the Reuss can still be traced in places along the valley near Zug, but they slope in the reverse way to the valley. From this and other evidence it is concluded that there has been a relative elevation of the land. The natural course of the river (which ran originally by Schwyz, through the Lake of Lowerz and the Lake of Zug, rejoining its present course by the valley of the Lorze) was thus changed, and it was turned west till it joined the Aa. The foldings in the neighbourhood of Lucerne changed the combined streams into a branching lake. The bays of Alpnach and Küssnach are a continuation of the valley of the Sarnen Aa, which forms the Lake of Sarnen. The peculiar shape of the Lake of Lucerne is thus accounted for:—The stretch from Buochs to Brunnen is probably the old course of the Engelberger Aa, when it joined the ancient Reuss at Brunnen and continued with it by Schwyz and Zug; the bottom of the Bay of Uri, where the Reuss enters the lake, is nearly flat, its two sides being reflections one of the other, and it appears to be a river-valley—a part of the course of the Reuss. Between Kindlimord and Schwybbogen a moraine crosses the lake, rising to within 164 feet of the surface.[2]

Lake of Zug has an area of about 15 square miles, a maximum depth of 649 feet, contains about 113,059 million cubic feet of water, and lies 1368 feet above sea-level.

The River Linth, a tributary of the Aar, drains the Lake of Walen and the Lake of Zürich, and under the name of Limmat flows into the Aar a little north of the junction with the Reuss.

Lake of Walen is about 10 miles long, by $1\frac{1}{2}$ miles in maximum breadth; the area is about 9 square miles, and the maximum

[1] *Beitr. z. geol. K. d. Schw.*, xxxi., 1891.

[2] Heim, *Beitr. z. geol. K. d. Schw.*, xxv., 1885.

depth is 495 feet, the mean depth being 338 feet, and the cubic contents about 87,947 million cubic feet. It lies about 1378 feet above sea-level. The shores on the south side slope steeply, and on the north side are almost perpendicular, the cliffs rising to a height of nearly 3000 feet.

Lake of Zürich lies 1341 feet above sea-level, and is about 26 miles long, by 3 miles in greatest width, the area being 34 square miles. The maximum depth is 469 feet, the mean depth 135 feet, and the volume of water about 137,748 million cubic feet. It is said by some geologists to be a river-valley, the lower end of which has risen relatively and is dammed by a moraine. It was excavated by water in pre-glacial times, and subsequently occupied by the glacier, the lateral moraine of which forms the low range of hills to the west of the lake. Glacial deposits form the ridge which constitutes the lower lip of the lake, and the river has cut through the ridge to a depth of 36 feet, so that the lake must have formerly stood at that height above its present level, and must have been joined to the Lake of Walen, from which it is separated only by a flat plain.

Lubbock [1] says that the valley of the Limmat was once occupied by the Rhine, and perhaps originally by the Sihl; the Linth, or Upper Limmat, then flowed through what is known as the Glatthal, until the great Rhine glacier, pressing westwards, drove it into the valley occupied by the Sihl, and, subsequently retreating, left the Glatthal a deserted valley, now traversed only by the little stream of the Glatt.

The valley of the Rhone, from the glacier where it takes its rise to the Lake of Geneva, forms the Canton of Valais, and that part of the valley lying between the gorge of St Maurice and Villeneuve was evidently at one time part of the Lake of Geneva, and would be so still if it were not for the deposits brought down by the Rhone. At and round Sierre are the remains of one of the most gigantic rock-falls in Switzerland, which must have dammed up the valley for a long time, but is now completely cut through both by the Rhone and by several tributary streams. The surface is very irregular, and has many small lakes in the depressions, the largest of which, a little north of Geronde, is about five-sixths of a mile long, by about a quarter of a mile broad. It lies 10 feet below the level of the Rhone, and has a depth of about 32 feet.

Lake of Geneva (or Genfer See, or Lac Léman) is the largest lake in Switzerland, and acts as a filter and regulator of the river, which enters with remarkably turbid waters and leaves as a clear stream. In times of flood the level of the lake gradually rises, and the fluctuations of the lower course of the river are thus kept within moderate bounds by the regulating action of the lake. It is

[1] *Op. cit.*, p. 391.

45 miles in length, by nearly 10 miles in breadth, and has an area of 225 square miles. The greatest depth (about midway between Lausanne and Evian) is 1015 feet, and as the surface lies 1200 feet above sea-level, the bottom is less than 200 feet above sea-level. Moreover, the lake-floor is covered by deposits to an unknown depth, so that originally it was probably much below sea-level. The material brought down by the river has not only raised the bottom of the lake, but has diminished its area by filling it up in part; formerly it extended at least to Bex, north of St Maurice. The mean depth of the lake is 506 feet, and the volume of water contained in it is estimated at about 3,175,000 million cubic feet. This lake has been studied systematically for many years, and forms the subject of a classic memoir by Forel.[1] Most of the promontories round the lake are river-cones, which are specially marked between Vevey and Villeneuve, and at the mouth of the River Drance, near Thonon, there is a typical delta. The eastern end of the lake is known as the Haut Lac, the centre as the Grand Lac, and the narrower western end as the Petit Lac. The Haut Lac is a transverse river-valley cut out by the Rhone, and subsequently, owing to a change of level, partly filled up again; the Petit Lac is the river-valley of the Arve. These two rivers met the River Drance opposite Morges, and the combined stream ran north to the Lake of Neuchatel. The elevation of the land then dammed back the water, giving rise to the Lake of Geneva, and lastly the cutting of the gorge at Fort de l'Ecluse gave the lake its present exit to the west, and gradually lowered its level.

Iceland. **Lake Thingvallavatn**, in the south-west of Iceland, is the largest and best-known lake. It covers an area of 40 square miles, and has a depth of 364 feet. It derives its water chiefly from the ice-field of Lang-Jökull, though one small stream, the Oxara, runs through it. The lake is said to be due to earth-movements, as its south-western shore is part of a long fault scarp.

Lake Thonsvatn, the second largest lake on the island, with an area of 38 square miles, occupies a basin formed by subsidence in an area of volcanic tuffs.

Lake Hoitárvatn is filled with fragments of ice from two glaciers which extend into the water.[2]

Asia. All the large northern Asiatic rivers take their origin in the marshes and lakes scattered over the surface of the plateaus which occupy the centre of Asia.[3] It seems probable that the water which

[1] *Le Léman: Monographie limnologique*, 3 vols., Lausanne, 1892–1904.

[2] Bisiker, *Across Iceland*, London, 1902.

[3] See p. 526.

accumulated there in a past epoch, and ultimately found its way to the ocean in a north-westerly direction as the rivers Yenisei, Selengá, Vitim, etc., formed first a succession of large lakes along the inner base of the range bordering the plateaus, traces of which are still seen in Kosso-gol and Lakes Shaksha and Bahunt. The overflowing streams from these lakes cut their way through the range and formed another series of lakes on the outer side. These in turn overflowed, and the waters subsequently found their way to the sea.

Lake Telezkoie (or Altyn Kol) was surveyed in the summer of 1901 by an expedition under Ignatov.[1] The lake lies in a narrow valley at an elevation of 1700 feet above the sea, has a length of 48 miles, with a breadth of 33 miles, the widest part being in the south, and covers an area of about 880 square miles. The main portion of the lake runs north and south, the Chulishman River entering at the southern end, while the Biya, which makes its exit at the north-west end, joins the Katun to form the Obi. Tectonic causes have evidently contributed to the origin of the lake. The result of 2500 soundings is to show that it is shallow in its northern section, but reaches a depth of about 1017 feet in the south. There are two deep basins, separated by a submerged ridge, over which the depth is 870 feet. In the middle of June 1901, the surface temperature was 39° Fahr. (3°·9 C.), and the temperature of the lower layers 37½° Fahr. (3°·1 C.), while the temperature of the inflowing streams was 48° to 57° Fahr. (8°·9 to 13°·9 C.). About the middle of July the surface temperature was 53½° to 61° Fahr. (12° to 16°·1 C.). The shallow portion freezes over in November; the deep southern portion is rarely frozen over—perhaps once in seven years. River Obi.

Zaisan Lake.—The great tributary of the Obi, the Irtish, gathers its head streams in the Zaisan Lake, 80 square miles in area, lying at an elevation of 1350 feet in a valley of the Altai.

Lake Baikal.—The largest lake of this system is Lake Baikal, a deep, long trough in the crystalline mountains, drained by the Angará, a tributary of the Yenisei. Different authorities give varying figures for the dimensions of the lake, but those of Schokalsky[2] are given here as representing the most recent survey. The length is over 370 miles, the breadth over 50 miles, and the area is about 11,580 square miles; the altitude of the surface is 1588 feet above sea-level, and the bottom of the lake is 3825 feet below sea-level, the maximum depth being 5413 feet—said to be the greatest depth in any lake. The River Yenisei.

[1] See *Globus*, Bd. lxxxi. p. 34, 1902.

[2] Schokalsky and Schmidt, *Explorations scientifiques des Mers et des Eaux douces de l'Empire russe* (Section Scient., Exp. Maritime Intern., Bordeaux, 1907).

lake-basin at one-third of its entire length from the south-west end is divided into two parts by a submerged ridge, covered by not more than 942 feet of water. Near the shore are considerable areas where the water has a depth of only 120 feet; the largest of these areas occur off the mouth of the Selengá, which brings down so much sediment as to form an immense alluvial cone, the Chivirkúlskaya Bay, the delta of the Upper Angará and the Little Sea; yet only 8 per cent. of the lake-floor is covered by less than 30 fathoms (180 feet) of water. Except off the deltas and the small Ushkanii Islands (near Svyatoi Nos Peninsula) the 100-fathoms line runs very near to the shore, especially along the north-western coast. Svyatoi Nos (Holy Cape) is a large peninsula protruding from the eastern shore of the lake opposite to the island of Olkhon, about midway between the northern and southern ends. The extreme northern end of the peninsula presents a high, wooded, almost vertical ridge with a craggy summit, from which flows a liquid called "Imushá" by the Tungús, natives of the district. According to Georgi,[1] it is a kind of mineral oil (vitroleum unctuosum): others believe it to be produced by the decomposition of the excreta of cormorants, herons, sea-gulls, and other birds, which come to the island in infinite numbers, mainly during their migration. Springs containing an oily liquid very much like naphtha have been discovered at the bottom of the Baikal opposite to the mouth of the River Túrka. Floating wax, or "bikerit," used by the inhabitants as a medicine for rheumatism and scurvy, is got on the surface at this part. It burns very quickly with a bright flame, and leaves much soot. This substance was subjected by Shamárin in Irkutsk to analysis by dry distillation, and volatilised at 140° C.; it contained 8·44 per cent. of liquid distillate (burning oil) and 61·17 per cent. of solids (paraffin of the best quality).

The numerous rocky fragments torn from the mainland found all round the lake, the islands lying in close proximity to the shore and retaining traces of their former identity with the surrounding mountains, and the great depth of water near the cliffs rising above its surface, all testify to the violent origin of the lake. Georgi[2] believes that the area occupied by it is the continuation of the valley of the Angará, and that the basin of the lake was formed by a sinking produced by a violent earthquake.

Kropotkin[3] considers Lake Baikal a "twin lake," the north end of the southern basin being continued by the valley of the River Barguzin, and the south end of the northern basin lying behind the

[1] *Guide to Great Siberian Railway*, p. 330, St Petersburg, 1900.

[2] *Ibid.*, p. 331.

[3] Cited by Suess, *Das Antlitz der Erde* (English translation, vol. iii. p. 53, Oxford, 1908).

island of Olkhon. He also says that the position of the River Selengá, which enters the lake at right angles on the eastern shore, and that of the river Angará, which leaves Lake Baikal, also at right angles, on the western shore, seem to indicate that they have once been parts of a single stream which was cut in two by the formation of the lake.

Chérsky[1] reckons 336 tributaries to the lake, the most important of which are the Upper Angará, the Selengá (which descends from the basin of Lake Kosso-gol), the Barguzin, and others; the only visible outlet is by the Lower Angará, a tributary of the Yenisei.

The water of the lake is clear and transparent, so that the bottom can be seen at a depth of 8 fathoms. The hydrography of Lake Baikal was studied by a commission under Drizhenko. Previously the lake had been regarded as one approaching very nearly the polar type, because observations at deep places were almost lacking. According to Vosnessensky,[2] director of the meteorological and magnetic observatory of Irkutsk, it ought to be relegated to the category of lakes of the temperate type. Inverse stratification exists only during the cold period of the year (December to June); in summer (June to December) it is direct. At the beginning of the months of December and of June the thermal layers become uniform, and the temperature from the surface to the bottom hardly varies, remaining very near the temperature of maximum density. All these changes occur only in the layer from 0 to 1000 feet; deeper than that the temperature remains constant. In the superficial layer from 0 to 50 feet the influence of different factors on the vertical distribution of temperature is apparent—depth, nearness to the shore and to the mouths of great rivers. In the deeper layer, from 50 to about 1000 feet, the temperature is very uniformly distributed over all the area of the lake.

Owing to the sudden changes of wind, to the fogs, and to the want of protected bays, navigation on Lake Baikal is difficult. From the end of May to the beginning of July a north-east wind with the local name of "Barguzin" blows on the southern part of the lake, and from August there is the "Kultak" coming also from the north-east. The strongest winds are called "Sorma," and blow from the north-west, producing short but high waves, which sometimes rise to the height of 4 feet. During storms, which occur frequently but are of short duration, the waves of the Baikal rise to 6 or 7 feet. In June and July the Baikal is almost calm, and during this lull numerous aquatic plants float on the surface of the water. The lake begins to freeze in November, but it is never frost-bound before the middle

[1] *Guide to Great Siberian Railway*, p. 331.

[2] See Schokalsky and Schmidt, *Sur les Explorations scientifiques des Mers et des Eaux douces de l'Empire russe*, p. 48, 1907.

of December or the beginning of January. It remains bound for a period of four to four and a half months, the ice-cover being sometimes 9½ feet thick. Wide cracks in the ice appear at intervals, and on the broken sheets coming together again the ice is piled up in heaps, called "toros." These crevasses, which have a breadth of from 3 to 6 feet, or more, are sometimes about half a mile long, and form a serious impediment to communication. Sledge traffic lasts for three months, but at the end of April the ice melts near the shore and softens. The breaking of the ice-surface, as in the Alpine glaciers, is accompanied by a loud crash, recalling an explosion, followed by a rumbling noise. The crack is instantly filled with water to the level of the ice-surface, forming a kind of river. In eight to fourteen days it freezes again, and a new crack appears at another place. The ice melts slowly, the process lasting nearly two months.

The fauna of Lake Baikal bears a close resemblance to the marine fauna,[1] but on account of the great distance of the glacial Arctic Ocean and of the Pacific Ocean, it is difficult to suppose that the fauna of the lake had any connection whatever with the oceanic fauna, and besides its waters are quite fresh. The German geographer, Peschel,[2] holds that Lake Baikal was in time past a gulf of the glacial Arctic Ocean, which in the Tertiary epoch probably covered the whole of Eastern Siberia. The German geologist, Neumayer[3] sustains this opinion, according to which Lake Baikal is a relict lake. Chersky refutes this, and says that the Arctic Ocean did not extend so far. Hoernes, on the other hand, points out the resemblance of the molluscs of the family Hydrobiidæ to the fossil shells supposed to have been derived from the great inland sea, Sarmate, which stretched from Graz and Kraïna to the mountains of Thian Shan, and covered almost all Central Russia in Miocene and Tertiary times.[4] A third view is that of Androussoff, according to which the great depth of Lake Baikal, and the similarity of its external conditions to those of the sea, might enable the fresh-water crustacea to form original species resembling marine forms. These are, of course, only hypotheses, but the fauna of the lake is very interesting[5] from the theoretical point of view, and merits further study.

A most interesting and little-known fish, characteristic of the

[1] See Schokalsky and Schmidt, *op. cit.*, p. 50.

[2] *Ibid.* [3] *Ibid.*

[4] Bogdanovich (*Works of the Tibet Expedition*, 1889–90, vol. iii. p. 60) says that the fossils from the mountains near Kashgar, described by Stoliczka as Triassic and taken as confirming the supposition of the existence of the Sarmate Sea in Mesozoic times, were in reality Devonian. There appears to be no trace of either a Mesozoic or a Tertiary sea in that area, and it may be assumed that Central Russia has not been under the sea since Palæozoic times.

[5] See p. 359.

Baikal, is the Dracunculus (*Comephorus baicalensis*), in which the head occupies a third of its entire length; the eyes are uncommonly large and protruding; from the gills to the tail, fins are attached on each side. This fish occurs in the deepest parts of the lake; it is said no one ever saw a living specimen. The lake abounds in crustaceans and gasteropods. There are four kinds of sponges of a dark emerald colour, containing much chlorophyll.[1] The seal (*Phoca baicalensis*) is called "nerpa" by the local inhabitants, and is killed during the whole summer.

Lake Kosso-gol.—One of the tributaries of the Selengá River is the Eke-gol, which drains Lake Kosso-gol, in the mountains south-west of Irkutsk. This lake is 83 miles long by about 25 miles broad, with an area of about 1300 square miles, and lies about 5470 feet above sea-level. The maximum depth, as shown by soundings taken by Peretolchin,[2] is 676 feet, the mean depth about 500 feet. The bottom of the lake-basin is fairly level, and its sides steep. In August 1897 the surface temperature was 59°·2 Fahr. (15°·1 C.) in the northern part of the lake, in August 1899 54½° Fahr. (12°·5 C.) in the centre (near Dola-Koi Island), and in July 1900 46° Fahr. (7°·8 C.) in the south. The temperature at 33 feet was 44°·6 Fahr. (7°·0 C.) in 1897 and 43° Fahr. (6°·1 C.) in 1900; at 300 feet, about 38½° Fahr. (3°·6 C.) in 1899 and 1900. In the cold summer of 1902 the surface temperature was only 41° Fahr. (5° C.) near Dola-Koi. Kosso-gol belongs to Forel's temperate type of lake, *i.e.* the temperature in summer is above that of maximum density, in winter below it. The lake freezes at the beginning of December, and becomes free from ice in June or July; the thickness of the ice is from 3 to 5 feet. The air temperature is low on the shores, daily means above 55° Fahr. (12°·8 C.) not being recorded until the end of July. The transparency of the water is very remarkable, the limit of visibility being 80 feet.

Lakes Tung-ting and Poyang are expansions of the mouths of the two chief southern tributaries of the Yang-tse Kiang. River Yang-tse Kiang.

Tung-ting Lake, in the province of Hoo-nan, is the largest lake in China. It is about 75 miles in length, from 20 to 37 miles in breadth, and about 1930 square miles in area, but varies much with the seasons. In ancient times it was called the Lake of the Nine Rivers, from the fact that nine rivers flowed into it. During winter and spring the water is so low that shallow parts become islands; but in summer, owing to the rise in the waters of the Yang-tse Kiang, to which it drains, the whole lake-basin is flooded. The

[1] *Guide to Great Siberian Railway*, p. 333.

[2] *Petermann's Mitt.*, Bd. l., p. 152, 1904.

lake receives the waters of many rivers, the principal being the Siang-Kiang.

Poyang Lake.—Another large lake, 70 miles in length by 40 miles in greatest breadth, with an area of about 1640 square miles, connected with the Yang-tse Kiang river basin is Poyang, which is traversed by the River Kan-Kiang. This lake, which drains nearly all the province of Kiang-si, is subject to great fluctuations in size and depth, and acts as a regulator of the Yang-tse Kiang.

Lake Tien-Chi (or Kunming), in the province of Yun-nan, is about 40 miles long, and is also connected with the Yang-tse Kiang by the Poo-to River.

River Hoang-ho.

Oring-nor and **Jaring-nor** are the names given to the lakes of the Upper Hoang-ho by most Mongols, but the Russians have called them Lake Russian and Lake Expedition.[1] Both are fresh-water basins, 13,900 feet above sea-level, separated from each other by a hilly isthmus nearly 7 miles broad. Oring-nor, the eastern lake, is about 80 miles in circumference, and Jaring-nor about 66 miles. The latter was not sounded, but appears to be shallow from the fact that wild yaks were seen wading across it; the former, according to measurements taken by Laduigin along its longer axis, was 105 feet deep at a distance of about 7 miles from the place where the Upper Hoang-Ho, or Yellow River of Eastern Tibet, flows out from it. On 23rd June 1900, the surface temperature of Oring-nor was 47°·7 Fahr. (8°·7 C.) to 53°·8 Fahr. (12°·1 C.), and the bottom temperature 46°·0 Fahr. (7°·8 C.) to 46°·8 Fahr. (8°·2 C.).

India.

Kolar Lake, a fresh-water lake in the Madras Presidency of India, midway between the deltas of the Rivers Kistna and Godavari, drains east into the Bay of Bengal. It abounds in water-fowl, and at dry seasons traces of ancient villages are perceptible in its bed. The area of the lake in the monsoon extends to more than 100 square miles, but it is becoming greatly reduced by reclamation and embankments.

Siam.

Tonle (or Tale) **Sap** (literally "inland lake"), a large lake in the north-west of Cambodia, serves as a reservoir for the surplus waters of the Mekong River, and consequently varies greatly in size and depth according to the season. During the dry season it is drained south-east by a branch of the Mekong, and has a length of 70 miles and a depth of from 2 to 4 feet; during the summer monsoon it is fed by the same branch, and increases in length to 120 miles, with a

[1] Kozloff, "Through Eastern Tibet and Kam," *Geogr. Journ.*, vol. xxxi. p. 529, 1908.

depth in places of 50 feet. It is also fed by streams from the Pnom Dangrik range to the north and from the west. It consists of two basins divided by narrows; the north-western being called Caman Dai, and the south-eastern Caman Tien. Fishing is carried on to a great extent in its waters during the season of low water.

Toba Lake.—In the mountainous regions of Sumatra are numerous lakes, much the largest of which is Lake Toba, lying at an altitude of between 2500 and 3000 feet above sea-level. It trends in a north-west and south-east direction, and is about 50 miles in length by about 16 miles in average breadth, with an area of about 800 square miles. The mountains surrounding the lake are high, with very steep slopes, and the small streams running from them in short, rapid courses are the only visible affluents. The outflow is by one of the head-streams of the Assahan River, which flows to the Malacca Strait. The lake is divided into two basins by a large island, the water between it and the western shore being so shallow that it is possible to ford it on foot at times of low water.[1] Sumatra.

The lakes of Eastern Africa belong to two types, the one circular in shape, with shelving shores, like the Victoria Nyanza, the other long, narrow, and fiord-like, lying between high, precipitous cliffs, like Lake Tanganyika. The latter type occurs on two lines of depression passing one on either side of the Victoria Nyanza and meeting at Basso Narok (Lake Rudolf), thence continuing northward to the Red Sea as a long strip of low land, in places below the level of the sea, with many lakes and old lake-basins occurring at intervals. At the northern end of the Red Sea the Gulf of Ákaba leads to a valley with the same structure, and thence to the plains of Northern Syria. The eastern and western portions of this long depression are to some extent linked together by a subsidiary valley lying farther to the east, which contains Lake Rukwa and enlarges towards the south to form the bed of Nyasa. Suess considers that once the plateaus which now form scarps on either side of the depression were continuous; volcanic action left dominant lines of weakness running almost parallel from north to south, and subsequently faulting along these lines allowed the block of material between to subside, leaving a great open rift valley with almost vertical sides. AFRICA.

Though Suess has many followers in his conception of the formation of what has been termed the "Graben" or Great Rift Valley, Moore, who visited the region in 1896 and 1899, does not share his views, but regards the depression as a consequence of the folding due

[1] See J. von Brenner, "Besuch bei den Kannibalen Sumatras," Würzburg, 1894 (reviewed by Baron A. von Hügel, *Geogr. Journ.*, vol. vii., p. 75, 1896).

to lateral pressure, which has also given rise to the great central ridge running from the mountains of Abyssinia and those flanking the Red Sea in the north to the continuation of these same ridges in the shape of the Drakensberg Mountains in the extreme south.

The lakes on the line west of the Victoria Nyanza—Tanganyika, Kivu, Edward, and Albert—drain to the Congo or the Nile, but those on the east and those in the depression north of Lake Rudolf have no outlet to the sea. Properly speaking, the latter should have been referred to along with the lakes of the inland drainage areas of Northern Africa; but as they lie in one of the branches of this gigantic valley system, they are described after the lakes of the Nile, the Congo, and the Zambesi (see p. 618). These lakes were explored in 1893 by J. S. Gregory.[1]

Apart from the seasonal variations in level, most of the lakes of East Africa show periodic fluctuations, while some have supposed that a progressive desiccation of the whole region is traceable, tending to the ultimate disappearance of the lakes. Such a drying-up has no doubt been in progress during long geological ages, but is probably of no practical importance at the present time. The periodic fluctuations in the level of Lake Tanganyika are such that its outflow appears to be intermittent. After rising steadily for some years after 1871, a fall seems to have set in about 1879, which before the end of the century had carried the lake back within its natural bed. Within the same time the neighbouring Lake Rukwa has in great part dried up. Others of the East African lakes have on the contrary risen in level, Nyasa having been unusually high in 1896, and Rudolf in 1896–98; so that, if the fluctuations are due to variations of rainfall, these do not affect the whole lake-region simultaneously in the same direction. In the case of Victoria Nyanza, a variation to the extent of 5 feet has been thought to recur in periods of eighteen to twenty-five years. Since 1896 records of the seasonal variations have been kept at stations north of the lake, the maximum in the year having been so far about 15 inches.

River Nile. The Nile is a good example of an old river system (see fig. 73), the basin of which has been subjected to various earth-movements, and now, partly as a result of these, partly in consequence of the geological structure of the country through which it flows, presents the somewhat unusual spectacle of a river with two plain tracts at two very distant points and levels in its course. The valleys of the Bahr-el-Jebel and White Nile form the upper plain tract, and the valley of Egypt the lower. The latter is simply a cleft in the desert plateau, and is regarded as having been determined in the first instance by

[1] See *The Great Rift Valley*, London, 1896.

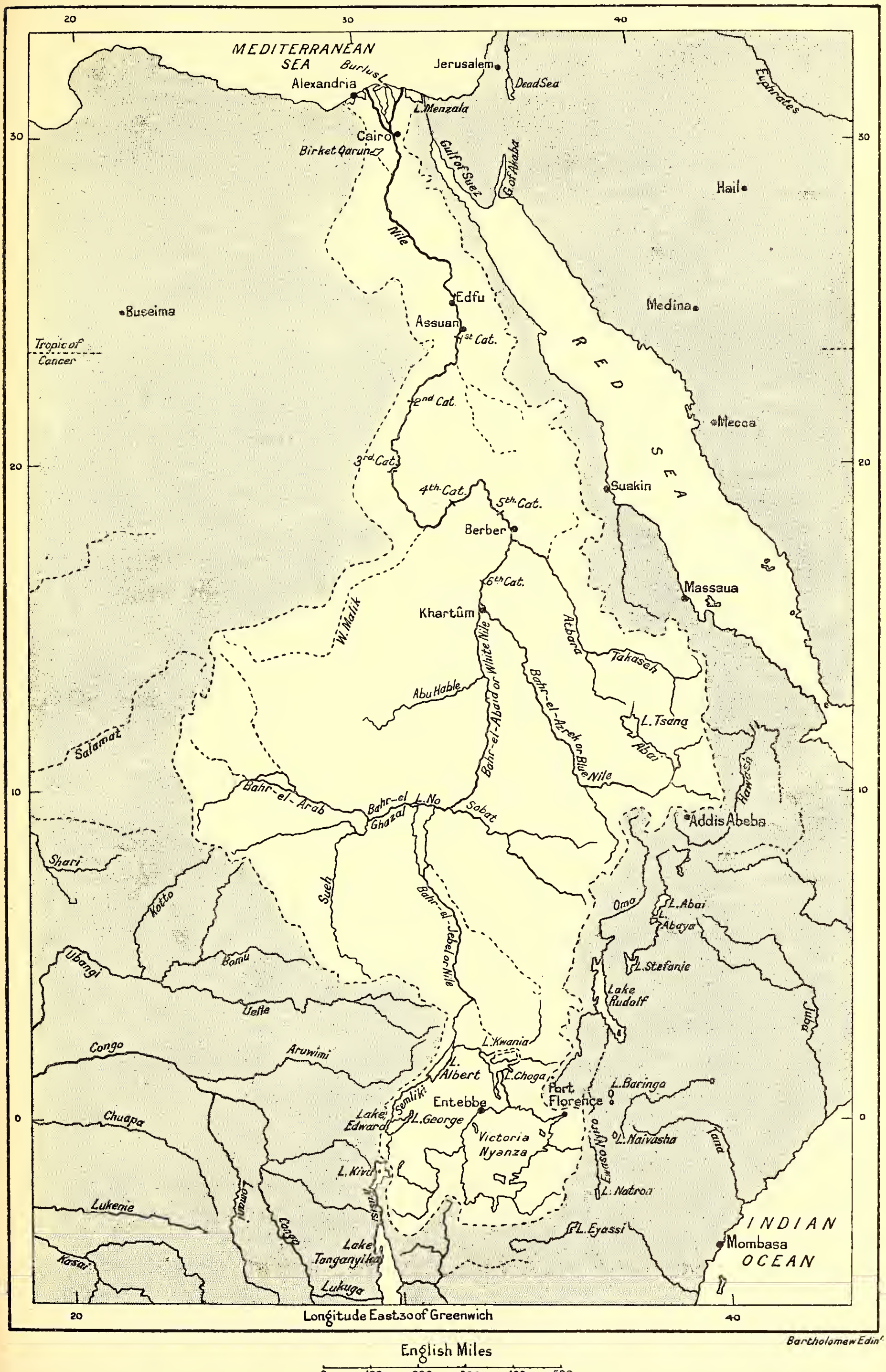

FIG. 73.—River Nile drainage basin.

fractures of the earth's crust, which caused a strip of country from about Edfu, in lat. 25° N., to Cairo, in lat. 30° N., to be depressed, leaving the plateau on either side standing high above it, just as the Red Sea and the Gulfs of Suez and Akaba are supposed to have been formed probably about the same epoch. Into this depressed area the drainage of the southern part of the basin finally flowed, and there was laid down during a long period the bed of alluvial deposit from 33 to 60 feet (10 to 18 metres) in thickness, through which the river runs to-day. The valley of Egypt is therefore the normal plain tract of the ancient river, and it is the portion intervening between that and the White Nile which gives indications of having renewed its youth.

The Nile rises in Victoria Nyanza, which occupies a shallow depression 26,248 square miles in extent on the plateau of the equatorial lakes, a region lying at an average elevation of from 4000 to 5000 feet above sea-level. That the earth-movements on the surface of the plateau are comparatively recent is shown by the moderate amount of weathering which has taken place, and by the incomplete development of the drainage system. As yet the rivers have not had time to deposit and erode sufficiently to give a regular grade to their beds, so that marshes and water-logged depressions still alternate with reaches in which the fall is considerable and the flow therefore rapid. The Victoria Nile, issuing from Victoria Nyanza, flows over the Ripon Falls, pours down 60 miles of rapids, to the still waters of Lake Choga. At Foweira 50 miles of rapids begin, ending at the Murchison Falls, 120 feet high; immediately beyond the material eroded from the rocky bed and brought in by tributary streams is forming extensive mud-flats where the Victoria Nile enters Lake Albert.

Victoria Nyanza.—The surface of Victoria Nyanza is 3720 feet above sea-level;[1] on its north side the land-surface descends gradually to Lakes Choga and Kwania, which lie at an altitude of about 3500 feet, and from there to Albert Nyanza, 2138 feet above sea-level. Victoria Nyanza, which has roughly the form of a parallelogram, being about 200 miles in length by 130 in average breadth, with an area of 26,000 square miles, is outlined by earth-movements, and there is definite evidence[2] furnished by the comparative readings of the lake-

[1] The heights given for the lakes dealt with are the trigonometrical heights taken from a paper by Capt. T. H. Behrens, R.E., on "The most Reliable Values of the Heights of the Central African Lakes and Mountains," *Geogr. Journ.*, vol. xxix. p. 307, 1907; those for Victoria and Albert Nyanzas are from a subsequent letter from Capt. Behrens published in the *Geogr. Journ.*, vol. xxx. p. 219, 1907.

[2] See H. G. Lyons, *Physiography of the River Nile and its Basin*, pp. 18, 43, Cairo, 1906. Lyons' conclusion is questioned by Craig (*Cairo Sci. Journ.*, April 1909).

gauges of a slight intermittent fall of the land during the period from 1897 to 1906, amounting in all to about 2½ feet. The proximity of the watershed to the lake (the head-waters of the streams flowing northwards to the Victoria Nile near Lake Choga are distant only from 16 to 20 miles from the lake shores) suggests the upheaval of a block along an approximately east-and-west axis, which cut off the drainage lying to the south, and so formed the present lake in the low-lying area between the more elevated ground east and west of it. The waters of the lake are in most parts shallow, the maximum depth being only about 240 feet.

Owing to the wide expanse of marsh and shallow lake which intervenes between the upper and lower portions of the Victoria Nile, the fluctuations in the level of Victoria Nyanza have no effect on the volume of water passing Foweira. These variations in level are divided by Lyons into several classes.[1] The first class includes those due to climatic changes, which affect the lake over long periods, and of which there is much evidence round Victoria Nyanza. Scott Elliot[2] attributes the flat alluvial plains which fill the valleys above the present lake-level to the detritus brought down by the tributary streams and deposited in the still waters of the lake. The second class includes the oscillations due to variations in meteorological conditions having a comparatively short period, such as that of about thirty-five years detected by Brückner,[3] in which a period of high levels is followed by a period of lower levels. Sieger[4] gives a table of the variations in level of the Central African lakes for different periods. Generally speaking, 1850 to 1878 would seem to have been a wet period, and 1879 to 1886 a dry one, for the whole of Africa; but from what the gauge readings on Victoria Nyanza teach, it is clear that lakes where evaporation is the main controlling factor, and the volume discharged is comparatively small, may vary considerably in level without any marked change in the average rainfall, since the lake-level responds quickly to any temporary increase or decrease of supply. The third class includes the annual oscillations which are due, in the case of Victoria Nyanza, to April and November rains. The fourth class includes the daily oscillations caused by the alternation of land and sea breezes, much more noticeable in landlocked gulfs like Kavirondo (Kisumu) than in more open situations, as at Entebbe. The fifth class includes seiches, of which no precise study has yet been made.

Lake Choga (or Kyoga), 3396 feet above sea-level, is a shallow

[1] *Op. cit.*, p. 33.

[2] See *A Naturalist in Mid-Africa*, p. 40, London, 1896.

[3] *Klimaschwankungen seit 1700*, Vienna, 1890; see also p. 528.

[4] *Bericht XIII. Vereins-Jahr* (1887) *Verein Geogr. Univ. Wien.*

sheet of water of irregular outline, with low marshy shores, ranging in depth from 13 to 30 feet. It extends about 50 miles in an east-and-west direction, and towards the eastern end breaks up into several long arms which receive the waters of other lakes lying on the plain west of Mount Elgon. Two of these, Lake Salisbury and Lake Gedge, form one sheet in rainy weather. The River Mpologomia, which flows into Lake Choga, and is one mass of papyrus at its entrance to the lake, has been described as a backwash of the Nile, and has been mapped as a swamp; but Purvis [1] says that after careful observation he has been able to map it as one of the chief rivers carrying off the waters from Mount Elgon to the lake, and thence to the Nile.

Edward and Albert Nyanzas.—The Albert Edward [2] and Albert Nyanzas, and the Semliki River which connects them, lie in the western arm of the great depression of East Africa and drain to the Nile; while Lakes Kivu and Tanganyika, farther south, send their surplus waters to the Congo. The dividing line between the north and south watersheds is now a range of volcanic cones which have blocked the valley between Lakes Kivu and Edward. It is believed that these are of comparatively recent origin, and that formerly Lake Kivu drained to the north—a view supported by the similarity observed between the living shells in Lake Kivu and the dead shells in the cuttings of the Ruchuru River flowing into Edward Nyanza, and also by the fact that the fauna of Lake Tanganyika is entirely distinct from that of Lake Kivu. Moreover, Lake Kivu is very deep, and the upper part of the gorge through which its outlet, the Rusisi, flows in leaving the lake is stated to be but little worn, so that the river is not of very great antiquity. When the volcanic dam north of Lake Kivu was first formed, its effects would be felt to the north much sooner than to the south, for it would mean that the whole drainage area of Kivu was cut off from the Nile. There is evidence in history that on the Upper Nile there existed huge lakes which have now disappeared, and it is quite probable that the shrinkage of the upper waters of the great river of Egypt which appears to have taken place is directly connected with the formation of the Kivu dam. After this dam was formed, not only must the Nile supply have shrunk by the loss of the very large amount of water collected from the Kivu drainage area, but the water to the south of the volcanic dam must have slowly risen year after year, and probably century after century, until it

[1] *Through Uganda to Mount Elgon*, p. 242, London, 1909.

[2] Albert Edward Nyanza is now to be called Edward Nyanza (or Lake Edward), so as to avoid confusion with Albert Nyanza (or Lake Albert). See *Geogr. Journ.*, vol. xxxiv. p. 129, 1909.

reached its present extraordinarily high level and overflowed into Tanganyika.

Cut off from the great drainage basin of Kivu, the waters of the Edward and the Albert Nyanzas fell considerably, as is evidenced by the old beaches and water-marks all along the shores of those lakes, reaching to 50 feet above the present water-level, till their altitudes are 3004 and 2028 feet respectively. Lyons[1] is of opinion that the shrinkage in the Edward Nyanza is in part due to its having cut down the barrier at its outlet, and he is led to this conclusion by consideration of the fact that the northern half of the Semliki valley is filled with clay, sand, and rolled boulders, while in the southern half low hills lie east and west, some of which may, as an elevated block, have once formed a transverse ridge or barrier across the valley through which the lake overflowed. In both Edward and Albert Nyanzas a large amount of detritus is being annually deposited by tributary streams.[2] Lake Albert is about 100 miles long by about 20 to 30 miles broad, and its area is approximately 2000 square miles. Lake Edward is roughly elliptical in form, about 50 miles in length, 30 miles in maximum breadth, and the area is approximately 1000 square miles. The arm of the lake situated on the equator is practically an independent lake (Ruisamba or Duero, now called Lake George) running to the north-east, and connected by a narrow channel with the main lake.

The Nile emerges from Lake Albert as the Bahr-el-Jebel, and is at first really an arm of the lake; in its course from Nimule, about lat. 4° N., to where the Bahr-el-Ghazal and the Sobat enter, it changes first to a tumultuous stream, with rapid succeeding rapid, and then north of Gondokoro to a river in its plain tract, with anastomosing channels and ox-bow lakes. The weed barriers, which form from time to time on the Bahr-el-Ghazal and give rise to flooded areas, sometimes not far short of 30 miles in breadth, are known by the Arabic term "sudd," signifying to dam. Much definite information about the sudds is now available, owing to the recent sudd-cutting operations, and Sir W. Garstin[3] describes them very fully.

Lake No, at the junction of the Bahr-el-Jebel and the Bahr-el-Ghazal, is a very moderate-sized shallow sheet of water, roughly 5 miles long by 2½ miles broad, and not as a rule more than 7 or 10 feet deep. In the rainy season, as the Sobat rises, it ponds back the discharge of the Bahr-el-Jebel, which is a small constant volume owing to the regulating effect of the swamps already explained, so that a reservoir is formed in the White Nile channel upstream from

[1] *Op. cit.*, p. 72.

[2] See W. Garstin, *Report on the Upper Nile*, p. 9, Cairo, 1904.

[3] Blue Book, *Egypt*, 2, 1902, p. 34, and *Report on the Upper Nile*, 1904, p. 109.

the junction of the two rivers, which cannot discharge itself until the Sobat levels have again fallen. At this time Lake No is enlarged by the flooding of the low-lying land on its shores.

The ponding back of one stream by another is also exemplified in the case of the Blue and White Niles. The Blue Nile, rising in Lake Tsana and descending from the Abyssinian hills as a red-brown torrent in time of flood, sweeps across from the point at Khartum to the opposite bank at Omdurman, pressing the White Nile against the western shore till it becomes just a long thin wedge, and ultimately is entirely cut off. The light yellowish-green waters of the White Nile break in gentle waves against the rushing stream as if it were a solid bank, and ultimately a placid lake is formed at the junction. A similar phenomenon occurs in connection with the Atbara, and these temporary lakes maintain the constancy of the Nile supply throughout the year, as the impounded water in one system takes the place of the flood-waters in another when these begin to fail, and the rivers thus automatically compensate one another.

Lake Tsana, with an area of about 1200 square miles, measures about 37 miles from east to west, and 45 miles from the mouth of the Magetsch to the outlet of the River Abai which issues from a bay on the southern side. The basin is a comparatively shallow depression about 5800 feet above sea-level, and the country on all sides rises gently at first to 6500 feet, and then more rapidly to 8000 and 9000 feet in the heights surrounding the lake. Stecker took 300 soundings from native boats, and found a depth of 236 feet between the islands of Dega and Zego, and a depth of 220 feet between Korata and the peninsula of Zegi. He says:[1] "The deepest places—in my opinion having a much greater depth than 100 metres (328 feet)—are to be found north of Dek, in the direction of Dega and Gorgora. One cannot, however, well venture to make an excursion to those parts in the fragile Abyssinian craft."

North of Berber the Nile becomes once more a mountain torrent with its course intercepted by rapids and cataracts, but in this case the geological structure of the country has determined the position, the extent, and the nature of these barriers. As the river has cut its way down through the overlying sandstone, it has met with portions of the crystalline rocks beneath, which have been greatly crushed by earth-movements and have developed lines of weakness. Along these lines the water rushes till it meets with obstructions to its flow, and thus the cataract portion is formed, stretching from Khartum to Assuan. Beyond Assuan the slope of the Nile is only 5 or 6 inches per mile.

The Nile branches at Cairo, discharging its waters into the

[1] See *Mitt. Afrik. Ges. in Deutschland*, Bd. iii. p. 32, 1881.

Mediterranean through two main arms and numerous subordinate channels. The lakes in the delta include Lake Mariut, 112 square miles in area, Lake Edku, 104 square miles, Lake Borollos, 266 square miles, and Lake Menzala, 745 square miles, which stand in hollows left by the failure of the river to fill its delta region up to a uniform level. The continual accumulation of fine silt raises the bed and banks of the stream until it flows in a channel a little above the adjoining country; thus a breach made during a flood overthrow diverts it to one side or the other, and in the new course so given the raising process and the breaking away are repeated. The various lines of flow are marked by higher deposits than the intervening spaces, and the interlacing of old channels encloses a very shallow, faintly marked basin.

The most remote head-stream of the Congo is the Chambezi, River Congo. which rises on the western slope of the plateau between Lakes Nyasa and Tanganyika, and flows south-west into the marshy Lake Bangweolo. Near the south point of that lake the river makes its exit through a vast marsh with isolated lakelets. It then turns north through Lake Mweru and descends to the forest-clad basin of western equatorial Africa; traversing this in a majestic northward curve, and receiving vast supplies of water from many great tributaries, it finally turns south-west and cuts a way to the Atlantic Ocean through the western highlands about latitude 6° South (see fig. 74).

Both Mweru and Bangweolo are merely shallow depressions which have been turned into lakes by the Upper Congo.

Lake Bangweolo, 3700 feet above sea-level, is of such uncertain area, owing to its shores being fringed with marsh and overgrown with papyrus, that it is useless to give any guess at the mileage of its open surface, but it must contain, Sir H. Johnston says, at least 1500 square miles of navigable water. The rivers running to it often flow through narrow swamps, many of which seem to have been at one time shallow lakes whose shrunken remains still show at places, like Lake Moir, near Serenji. These small swamps become larger and more frequent as the rivers approach one another, and at last become one vast dead-level morass, which in its north-western part changes from a dense mass of papyrus reeds to a sheet of open water, and is then known as Lake Bangweolo. The lake has covered a much larger area eastwards and up the Lukula, Chambezi, and Mansya Rivers, for the rivers that pour in on its north and east sides have been piling mud in its shallow bed for centuries and extending their deltas into it.

Lake Mweru, 3189 feet above the sea (Lemaire, 1901), is 68 miles long by 24 miles broad.

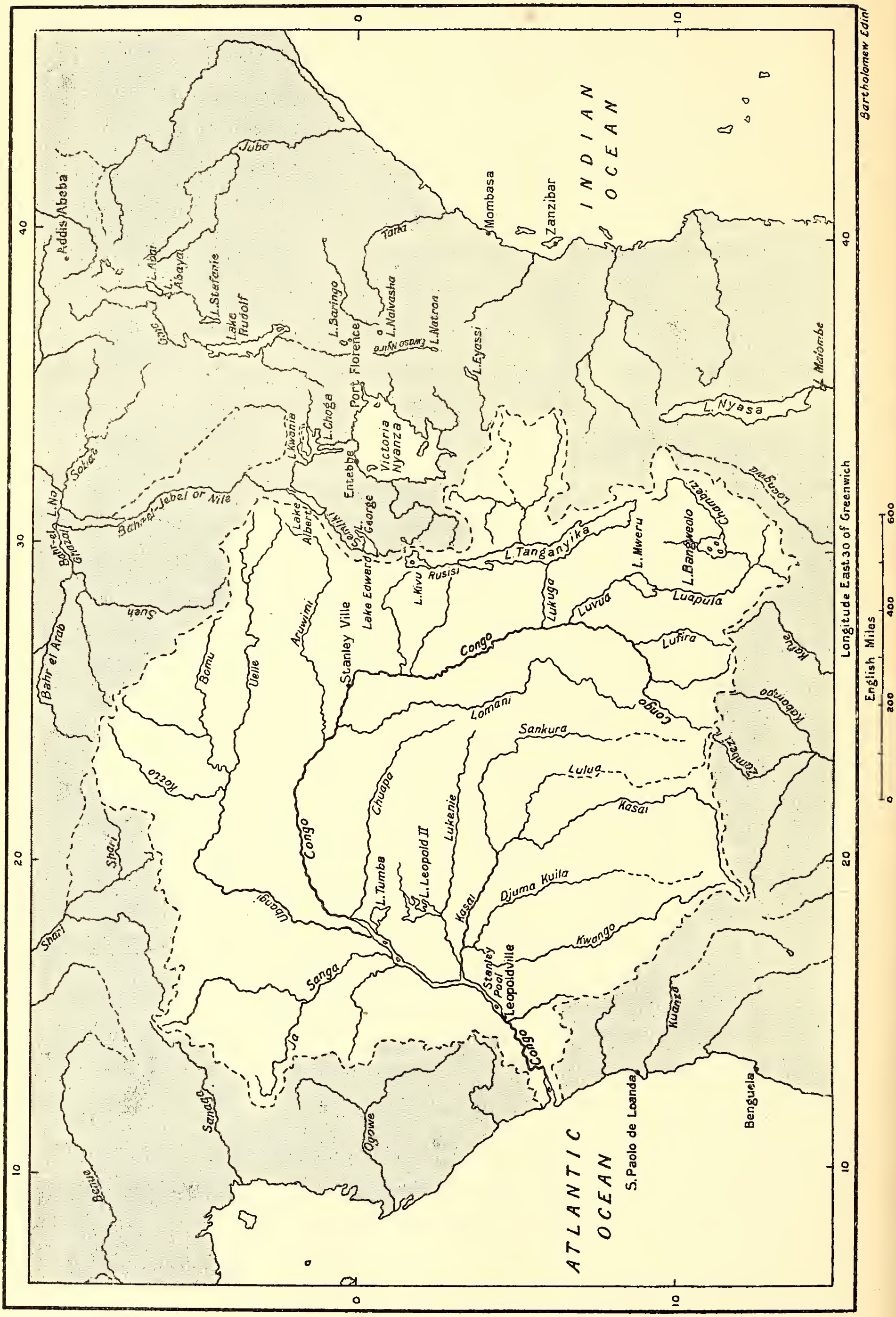

FIG. 74.—River Congo drainage basin.

Lake Tanganyika (or Tanganika[1]) is about 400 miles long by 30 to 60 miles broad, with an area of 12,700 square miles, and lies 2624 feet above sea-level. Little is known regarding the depth of the lake, as it has never been systematically sounded; but a depth of 2100 feet is reported by Giraud off Mrumbi, on the west coast, while Livingstone[2] states that he sounded opposite the high mountains of Kabogo, south of Ujiji, where he found 1956 feet, and Moore,[3] referring to a spot near the south end, speaks of 1200 feet and upwards.

Hore[4] found the water of the lake fresh, and considered that the taste resembled that of distilled water rather than that of spring water. Frankland, who made an analysis of samples brought home by Hore for the purpose, reported it to be similar to Thames water, but with very much less organic impurity. Moore[5] says the water of Tanganyika is somewhat salt, though it seems to be fresher now than when Livingstone and Stanley examined it; while, as both these explorers aver, there are traditions among the Arabs that in the recollection of living men it was a lake which never flowed out at all. To-day it drains intermittently by the Lukuga to the Congo, and it is a most remarkable fact that the outlet of Lake Kivu, the Rusisi, which flows into Lake Tanganyika, is five or six times larger than the Lukuga, the outlet of Tanganyika itself. If, therefore, the Rusisi River were cut off from Lake Tanganyika, that lake would altogether cease to overflow. Moore[6] argues from these considerations that probably, after the drainage of Lake Kivu had been turned away from Lake Albert by the formation of the volcanoes,[7] that lake overflowed into Tanganyika for a number of years, until the level of the latter was raised to such a degree that it in like manner overflowed and cut a channel to the west into the Congo. This view of the matter explains also the fact that there are everywhere indications that Tanganyika formerly stood at a much higher level. Cunnington[8] considers the water of Lake Tanganyika perfectly fresh and pure, and says that if, as has been suggested, there has been for ages some sort of periodicity in the forming and breaking of mud and vegetable barriers across the Lukuga River, we must be face to face with a lake in which the quantity of salts in solution has been and still is varying from time to time.

[1] See *Geogr. Journ.*, vol. xxvii. p. 411, 1906.
[2] *Last Journals*, vol. ii. p. 19, London, 1874.
[3] *The Tanganyika Problem*, p. 48, London, 1903.
[4] *Tanganyika: Eleven Years in Central Africa*, p. 146, London, 1893.
[5] *Op. cit.*, p. 90.
[6] *Loc. cit.*
[7] See p. 610.
[8] This and other references are to an unpublished memoir submitted by Dr Cunnington.

Native tradition appears to indicate that the valley of the Lukuga was originally formed by an affluent river, and that subsequently a river of the Congo basin rising on the other side of the divide worked its way gradually backwards, cutting through the ridge, and successively capturing the various tributaries of the other river, and finally the whole river-system. A connection having been thus established, it was an easy matter for the waters of the lake, on reaching the high level after the addition of the drainage from Lake Kivu, to drain away naturally westward to the Congo. Stanley [1] takes this view, but Moore [2] considers the bed of the Lukuga a continuation of the cross-valley in which Lake Rukwa lies.

A good many readings of the water-temperature of Lake Tanganyika were made by Cunnington,[3] and he concludes that the temperature in general must be very high, as the lowest reading obtained on the lake was 73°·3 Fahr. (22°·9 C.), while the highest was 81°·0 Fahr. (27°·2 C.). At a depth of 456 feet (the length of the sounding-line), readings taken on different occasions and at different spots only varied between 74°·1 and 74°·8 Fahr.

Attempts were also made to observe the seiches by means of an improvised apparatus. The principal series of observations taken lasted for eight consecutive hours, during which readings were made at minute intervals. From the curve obtained there appear to be oscillations with a period of about 60 minutes or a little under, which occur with some degree of regularity, and probably a seiche of longer period: $4\frac{1}{4}$ hours or a little over. The greatest amplitude noticed is only $2\frac{1}{2}$ inches (6·5 cm.). Unfortunately, sufficient details as to the depth and contour of the lake are lacking, so that the theoretical periods of the seiches cannot be worked out.

The aquatic plants of Tanganyika are in no respect unique, and in many cases the same species occur in Nyasa or Victoria Nyanza, or both. The fauna is remarkable not only as including forms of unusual character for a fresh-water lake, and possibly distinct in origin from the general fresh-water fauna of Africa, but as containing a much larger number of species than the other big African lakes. This seems to indicate that Tanganyika was long isolated, and at some former time had some connection with the sea. Moore believes this to have taken place in Jurassic times.[4] From the configuration of the continent he considers the only possible connection of Tanganyika

[1] *Through the Dark Continent*, vol. ii. p. 47, London, 1878.

[2] "Tanganyika and the Countries North of it," *Geogr. Journ.*, vol. xvii. p. 10, 1901.

[3] "The Third Tanganyika Expedition," *Nature*, vol. lxxiii. p. 310, 1906.

[4] "On the Hypothesis that Lake Tanganyika represents an Old Jurassic Sea," *Quart. Journ. Micr. Sci.*, N.S., vol. xli. p. 303, 1898.

with the Jurassic sea to have been in the west and north-west, through the basin of the Congo. According to Cunnington, this theory is supported neither by geological nor palæontological evidence, and he considers that in the present state of our knowledge it is impossible to put forward a convincing theory that will fit the facts of the case.

Lake Kivu lies at an altitude of about 4829 feet above sea-level, about 100 miles north of Lake Tanganyika, into which it drains. The lake is 60 miles long by 30 to 40 miles broad, and more than 600 feet deep; the area, including islands, is about 1100 square miles. It is roughly triangular in outline, the longest side lying to the west. Its waters are charged with saline matter to such an extent that the shores have become incrusted with a substance containing a high percentage of magnesium carbonate. Samples of this incrustation were examined under the direction of Professor Wynne, and only traces of calcium salts were found to be present. A calcareous tufa is found on the lake-floor deposited round vegetable debris, and also incrusting pebbles and reed-stems on the shore-line. The nodular incrustation is very hard, and was found on analysis to contain 28·65 per cent. calcium oxide and 12·66 per cent. magnesium oxide.[1]

Lake Leopold II. is described by Stanley[2] as a shallow depression in the lowland portion of the Congo basin caused by sudden subsidence. It discharges by the Ufini River into the Kasai, a tributary of the Congo.

Stanley Pool is an expansion of the Congo, about 25 miles long by 16 miles broad. The pool is a great cup-like basin with an incomplete rim formed by sierras of peaked mountains ranging on the southern side from 1000 to 3000 feet in height. The pool contains seventeen islands of some note.

Lake Nyasa.—The only great lake of this system, Lake Nyasa, drains into the Zambesi by the Shiré River. It extends from 9° 29′ to 14° 25′ South, or through nearly 5 degrees of latitude, and measures 350 miles along its major axis, which is slightly inclined to the west of north, while the greatest breadth, occurring near the middle of its length, is 45 miles. The total area is 14,200 square miles. It lies in a very long and relatively narrow valley, the surface of the lake, which is 1645 feet above sea-level, being far below the general level of the surrounding country. The depth of the lake seems to vary in accordance with the steepness of the shores, increasing from south to north. The greater part of the northern half shows depths of over 200 fathoms, while a maximum depth of 430 fathoms (2580 feet) was River Zambesi.

[1] See Moore, *The Tanganyika Problem*, p. 84, London, 1903.

[2] See *The Congo and the Founding of its Free State*, pp. 435 *et seq.*, London, 1885.

obtained by Moore in 1899 off the high western shore, in latitude 11° 40′ South. A more complete series of soundings, however, since made by Lieutenant Rhoades,[1] gives 386 fathoms (2316 feet) off the same coast, in latitude 11° 10′ South. The lake is bordered by three old beach terraces, of which the most marked lies 14 feet above the present water-level. Moore[2] considers that in all probability the wearing away of the floor of the Murchison Falls, over which the Shiré River carries the surplus waters of the lake, led to the lowering of the water-level. He says that Nyasa may at one time have been connected with Lake Shirwa, and both lakes have drained down the valley of the Lujenda River to the Indian Ocean.

In 1895 and 1899 observations were made on the fauna of Lake Nyasa by the Tanganyika expeditions, and it was discovered that beyond 100 to 150 feet the lake was practically a fresh-water desert, there being encountered in its deeper water nothing but organic refuse mixed with fine grey mud.

Lake Malombe, through which the Upper Shiré flows after leaving Lake Nyasa, had an area of 100 square miles in 1893, but in 1894 and the succeeding years a large sand island was thrown up in the centre and became covered with reeds, so that in 1896 the lake was little more than a broad channel of the Shiré River divided by the island from a narrower channel to the west. Sir H. Johnston[3] attributes much of the recent decrease in the volume of the African lakes to a slow and gradual upheaval of the land, and he thinks that the sudden change of this lake into a sandy marsh and broad river-channel supports his view.

Lakes of the so-called Great Rift Valley and other Inland Drainage Areas of East Africa.

Lake Natron, 1996 feet above sea-level, in lat. 2°·5 S., long. 36° E., is fed by streams from the west side of the rift and by numerous small streams impregnated with carbonate of soda. In 1903 Captain C. E. Smith[4] found it to be only 10 square miles in extent, but after the January and February rains it had spread over about 200 square miles of flats.

Lake Magadi, 2050 feet above sea-level, in lat. 1°·8 S., long. 36° E., receives one small stream of fresh water and two hot streams saturated with sodium carbonate. The lake is some 100 square miles in extent, and never more than a few inches deep. It forms a natural evaporating pan, and the soda dug from it is remarkably pure and abundant. Thousands of flamingoes and wading birds

[1] See *Geogr. Journ.*, vol. xx. p. 68, 1902.

[2] *The Tanganyika Problem*, p. 122.

[3] See *British Central Africa*, London, 1897.

[4] See "From the Victoria Nyanza to Kilimanjaro," *Geogr. Journ.*, vol. xxix. p. 258, 1907.

are to be found in it, hunting for a kind of small fish that lives in the mud.

Lake Elmetaita, in lat. 0° 25′ S., long. 36° 16′ E., receives two rivers, the Kariandusi and the Guasso Nagut, but has no outlet; its level is being lowered by evaporation. The water is bitter and salt, but clear and pure, and the only signs of animal life in it are some insect-larvæ and small crustaceans. Flocks of pink flamingoes feed on the masses of algæ, which in places impart a deep green colour to the water.

Lake Naivasha, measuring some 13 miles each way, is situated in lat. 0° 44′ S., long. 36° 24′ E., and is 6135 feet above sea-level; it receives a tributary, the Murendat, but has no outlet. Its basin is closed to the north by the ridge of Mount Buru, beyond which are the basins of the smaller lakes Nakuro and Elmetaita, followed in turn by those of Losuguta and Baringo.

Lake Nakuro, a salt lake in lat. 0° 20′ S., long. 36° 9′ E., at an elevation of 5668 feet, receives the Enderit.

Lake Losuguta, in lat. 0° 15′ N., long. 36° 8′ E., lies 3050 feet above sea-level, and is long and narrow. One shore is a precipice 1900 feet in height, and the opposite one is formed of a series of terraces which rise one above another to the summit of Doenyo Lugurumut. The waters of the lake are salt and sulphurous, and have emetic properties. No life is present in the lake, with the exception of dense masses of algæ (as in Lake Elmetaita), which form food for vast flocks of pink flamingoes. The putrid sulphurous waters seem to kill whatever they touch, the grass round the lake being yellow, and trees standing near the shore, though recently submerged, as shown by leaves still attached to them, being dead.

Lake Baringo, in lat. 0° 43′ N., long. 36° 6′ E., formerly had an outlet to the north, and was possibly one of the sources of the Nile; it is surrounded by raised beaches, indicating that it once stood at a much higher level. It is 3325 feet above sea-level, and the eastern wall is in places a single face of rock, 2000 feet in height. The length of the lake is about 18 miles.

Lake Sugota was described by Cavendish[1] in 1898 as a sheet of water situated between Lake Baringo and Lake Rudolf, 30 miles due south of the latter, at an altitude of 1300 feet, running north and south for about 25 miles, the southern portion trending in a south-westerly direction for about 10 miles. Its shores are very barren, he says, entirely enclosed by mountains, and three islands near the east shore are also barren. Near the north end of the lake a smouldering

[1] "Through Somaliland and around and south of Lake Rudolf," *Geogr. Journ.*, vol. xi. p. 392, 1898.

volcano, 1600 feet in height, called by the natives Sugobo, is situated. The lake is fed by two rivers, and before the volcano became active the water was good to drink, though now it is very hot; in places the water has evaporated, exposing a bed of deep black mud, hot, but with a hard crust of salt over the surface, while on the borders are solid mounds of salt. Former high-water marks are strewn with masses of bones and skeletons of fish large and small, evidently killed when the water became heated. On the other hand, C. W. Hobley,[1] writing in 1906, said:—"The enormous Lake Sugota of the Intelligence Division, Map No. 1429 (d), is non-existent, and it is difficult to understand how it became delineated. The Sugota River is bounded by great walls of lava, so could hardly have flooded the plains. It, however, may be that Cavendish or one of the earlier explorers saw the whitey natron deposits from the slopes of Mount Nyiro, and took them for water."

Lake Rudolf (Basso Narok, "Dark Water"), in lat. 3° N., long. 36° E., is over 200 miles long, about 3500 square miles in area, and lies at an elevation of 1250 feet above sea-level, its greatest depth being 25 feet. Dr Donaldson Smith[2] says it is not like a long sheet of water lying in an abrupt cut or fissure in the earth's surface, but is a shallow basin in open country, very much spread out except at the southern end. The beach is composed of black sand, and hence Lake Rudolf is termed Black Lake by the Swahilis, while Lake Stefanie to the north-east, the shores of which are of white sand, is called White Lake. The western shores of Lake Rudolf are characterised by numerous lagoons, separated from the open water by low sand-bars (thrown up by the action of the waves), which are frequented by many water-birds. Evidences were noted in 1898 of a western encroachment of the lake. Several rivers flow towards the lake, but do not always discharge into it; thus the Sacchi empties itself into a large area of swamp at the head of Sanderson Gulf before the shores of Lake Rudolf are actually reached, and the Keno and the Turkwell seldom reach the lake. It was generally concluded that the Omo was the only perennial feeder, but in 1899 Harrison[3] found that even that river was dry, and that the level of the lake had sunk 12 feet during the year. In three stages, each probably of about one year's duration, it had sunk 28 feet. Austin[4] says the waters are impregnated

[1] See "Notes on the Geography and People of the Baringo District of the East African Protectorate," *Geogr. Journ.*, vol. xxviii. p. 473, London, 1906.

[2] See "An Expedition through Somaliland to Lake Rudolf," *Geogr. Journ.*, vol. viii. p. 226, 1896.

[3] See "A Journey from Zeila to Lake Rudolf," *Geogr. Journ.*, vol. xviii. p. 272, 1901.

[4] See *Geogr. Journ.*, vol. xiv. p. 150, 1899.

with sodium (probably sodium carbonate is meant), but yet abound with fish, mostly cat-fish. Crocodiles and hippopotami were also found on the lake.

Lake Stefanie (Basso Ebor, "White Water"), in lat. 4° 30′ N., long. 37° 0′ E., about 1900 feet above sea-level, is 35 miles long, 15 miles wide, and not over 25 feet deep; in shape it is like a boot. Its Sagau affluent receives an overflow from Lake Abaya in times of flood. Dr Donaldson Smith[1] says the waters of the lake are quite fresh, though it has no overflow. In 1899 Harrison[2] found the lake dried up and covered with sand, and this may explain its freshness.

An almost continuous chain of lakes, some fresh, others brackish, some completely closed, others connected by short channels, extends from Lake Stefanie as far north as Lake Zuai.

Lake Zuai, in lat. 8° 0′ N., long. 38° 45′ E., is a fresh-water lake, and two distinct terraces of former shore-lines lie some 80 feet above the present level of the water. It is fed by the River Makee, and its outlet is the River Suksuk, which flows between cliffs of chalk 100 feet high, into the brackish Lake Hora, the shores of which are covered with a white crust of sodium carbonate. In rainy weather this lake is joined to Lake Sveta, lying to the east. Lake Hora drains into Lake Laminia, a very brackish lake.

Lake Abai.—Farther to the south is Lake Abai or Abba. These variants are used generically for any large mass of water. The Italians found its true name to be Pagade, and christened it afresh Regina Margherita. It is of great beauty, and contains twelve islands, all inhabited and cultivated. It is about 95 miles long, and receives from the north the waters of the Shashago River, and with them the drainage of a hot spring south of Lake Laminia; it sends a short effluent into Lake Abaya or Chiamo, lying to the south and draining in the rainy season into Lake Stefanie.

Lake Aussa, in lat. 11° 25′ N., long. 42° 40′ E., lies in the centre of a depression some 60 or 70 miles from the head of the Gulf of Tajura. It is fed by the Hawash, the principal river of Eastern Abyssinia, a copious stream nearly 200 feet wide and 4 feet deep at its junction with its chief tributary, the Germana. This lake is fresh, though the lagoons in the region are highly saline, with thick incrustations of salt round their margins.

Lake Assal is separated from the Gulf of Tajura by a sill only 12 miles wide, covered with a bed of lava containing several deep craters. It is about 7 miles long, and lies about 222 feet below the level of the sea. Several torrents flow into it, but there is no outlet. Its waters are very salt, and there are salt deposits round it; the level of the lake seems to be falling.

[1] *Op. cit.*, p. 224. [2] *Op. cit.*, p. 271.

Lake Rukwa, 2560 feet above sea-level, is a huge swamp formed by the collection of local waters. The waters of the lake are salt, and it seems liable to great variations in area and depth, as accounts of its size vary greatly. Its principal affluent is the River Saisi, which rises in the north of British Central Africa, but it has no outlet.

Lake Shirwa (or Chelwa), south of Lake Nyasa, is a large oval body of water, 1946 feet above sea-level, about 50 miles in length and 15 to 16 miles in average breadth, lying in a flat central depression of extensive lacustrine plains which were at one time portions of the floor of the lake. It is very shallow and has no outlet, though the rise of a few feet would cause it to drain through the Ruo into the Shiré and Zambesi. The fauna of this lake appears to have been at one time identical with that of Lake Nyasa, but owing probably to the rising of the ground, which has separated Lake Shirwa from Lake Nyasa and has finally resulted in Shirwa having no outflow, and hence becoming salt, the old Nyasa fauna has been killed out, except in the curious fresh-water oases which are still maintained at the mouths of the permanent rivers flowing into the lake.

North America.

The drainage system of the northern part of North America shows the former maturity of a region that has been recently glaciated. The effect of the invasion of the ice-sheet—which advanced from the north in the Pleistocene period in a south and south-westward direction—is visible as far as the northern half of the Mississippi valley. Ten or more important bodies of water lie in a curve from Lake Ontario to Great Bear Lake, and the lakes lying between that series and Hudson Bay, as well as those situated south and west of the lake-belt, are essentially depressions on new land areas; but, while the one region shows the destructive action of the ice, the other exemplifies its constructive action. The soil that the Eastern Canadian Highlands possessed in pre-glacial times has been stripped away, leaving a bare unweathered surface on which the ice has eroded numerous rock-basins. This area is covered with many lakes which lie in the hollows; the rivers draining them have not yet cut down their drainage slopes, and are interrupted by falls and rapids. On the other hand, the surface of the region farther south is heavily sheeted with glacial drift, so that for tens of miles not a ledge of rock is to be seen. Glacial deposits are so varied in character, and so irregularly laid down, that they abound in depressions that become filled with water, and it is chiefly in this way that the numerous small lakes of New England are to be explained.

Geological evidence seems to point to the fact that previous to the glacial epoch North America had been above the sea for a long period at a greater elevation than at present, especially to the north, and therefore had been subject to subaerial erosion. This old land-surface had a well-developed drainage system with many rivers flowing across it to the sea through broad valleys, in which the advancing ice-sheet subsequently deposited detritus that obstructed the flow so as to form important lakes.

River St Lawrence.

The problem of the origin of the Great Lakes of the Laurentian basin is not completely solved, but there are many facts that lead to the supposition that they lie in old valleys clogged by drift, and that glacial erosion played a comparatively minor part in their formation. Before the glacial epoch there was a system of river-drainage different from the present one,[1] but the lake-troughs were empty except along the deepest bottom line. The position of these troughs was determined by that of the more easily eroded rocks, which they follow with remarkable closeness, and their recent conversion into lakes has been accomplished by local concentration of drift in deep narrow valleys, where it could act effectually as a barrier. As the ice retreated from the region the sheets of water found one line of discharge and then another, leaving their record in the immense deposits of gravel dropped by the overloaded glacial streams, and in the numerous water-worn channels, too large for the streams which now occupy them, and without catchment areas commensurate with their size. During all the remarkable changes that ensued, the land to the north-east was slowly rising, and this change of level had much influence in determining the various lake-outlets. An examination of a number of authentic records by Gilbert[2] has shown that this rising still continues, and that there is a tilting of 0·42 foot in a hundred miles in a century. If continued, the banking or backing up of the waters at the southern end of Lake Michigan will go on much faster than the lowering consequent on the work of the Niagara River in wearing down the falls, and in two or three thousand years all the lakes but Ontario will be tributary to the Mississippi River, as they were during the period of the retreat of the ice-sheet. The history of the Laurentian basin, as read from the hard-rock topography of the region, has received different renderings, but the facts seem to go to prove that the basins of the Great Lakes were formed by a combination of erosion, warping, and obstruction.

A survey of the Laurentian lakes made by the Corps of Engineers, U.S. Army, between 1841 and 1881, is the basis of nearly all the accurate information now accessible concerning the physical features;

[1] See W. M. Davis, "Classification of Lake Basins," *Proc. Boston Soc. Nat. Hist.*, vol. xxi. p. 362, 1883.

[2] "Modification of the Great Lakes by Earth Movement," *Nat. Geogr. Mag.*, vol. viii. p. 245, 1897.

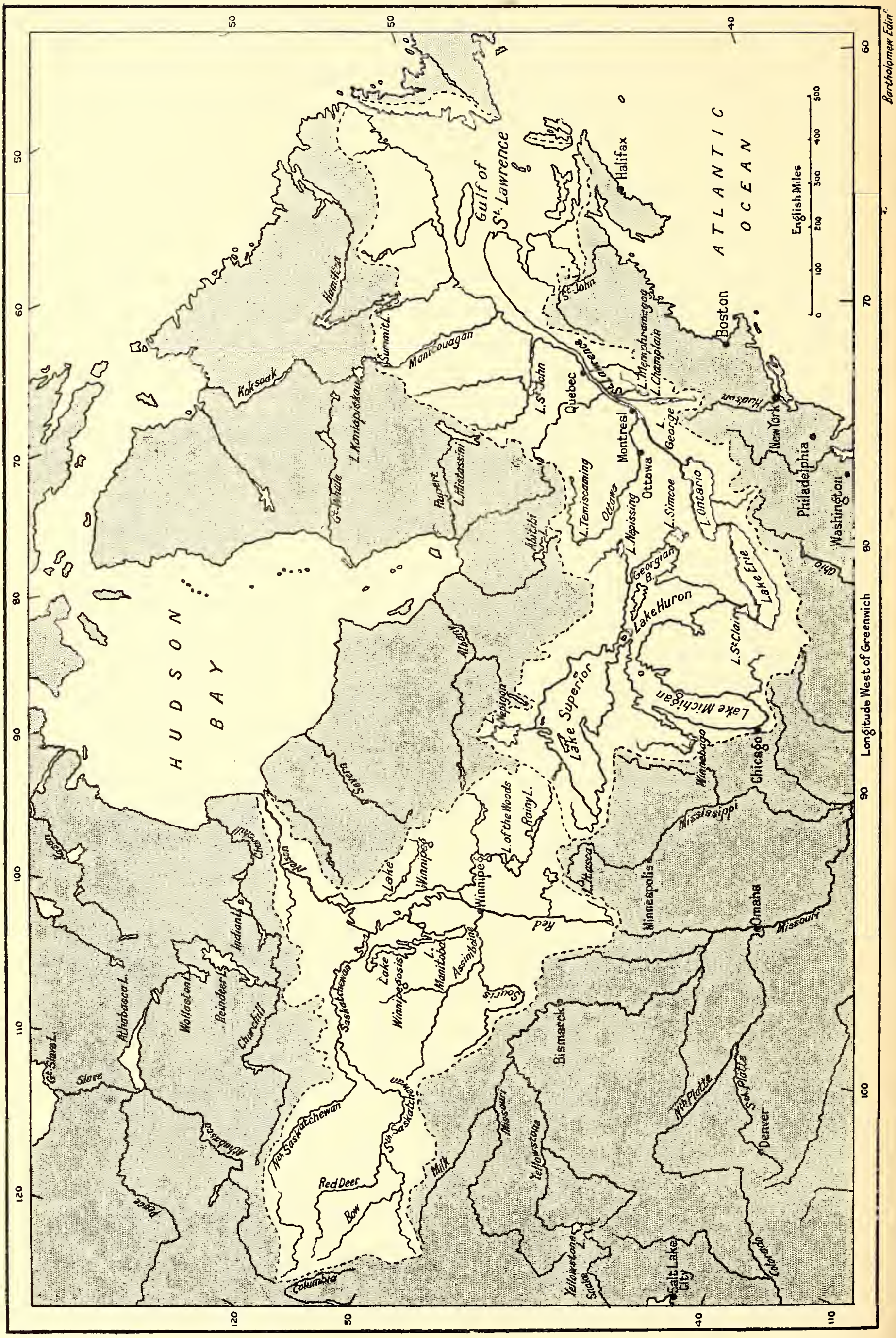

FIG. 75.—River St Lawrence drainage basin ; showing also those of the Rivers Nelson and Saskatchewan.

but owing to changes in the rivers connecting the various lakes, and also on account of the many harbour and canal improvements that have been carried out, a new survey of portions of the lakes has been made under the direction of General O. M. Poe. From the results of the former survey L. Y. Schermerhorn[1] has compiled some statistics regarding the Great Lakes, a few of which are quoted here; the measurements of the length and breadth of the various lakes not being given by Schermerhorn, those given by S. E. Dawson[2] are for the most part adopted.

Lake Superior, the largest body of fresh water on the globe, 627 feet above sea-level, has an area of about 31,200 square miles, a mean depth of 475 feet, and a maximum depth of 1008 feet. The length is about 400 miles, the circumference about 1500 miles, the maximum breadth about 160 miles. At depths exceeding 200 feet the temperature of the lake varies only slightly from 39° Fahr. (3°·9 C.) all the year round.

Lake Michigan has an area of 22,450 square miles, a mean depth of 325 feet, and a maximum depth of 870 feet; its surface is 581 feet above sea-level. The length is 345 miles, the maximum breadth about 90 miles.

Lake Huron, together with Georgian Bay, covers an area of 23,800 square miles. It has a mean depth of 250 feet, a maximum depth of 730 feet, and lies at the same altitude as Lake Michigan. It is 270 miles in length, and exceeds 100 miles in breadth. The temperature of the lake in the months of June and August at the surface and at depths of about 300 feet was 52° Fahr. (11°·1 C.), while at a depth of 624 feet the temperature was 42° Fahr. (5°·6 C.).

Lake Erie has a water surface of 9960 square miles, a mean depth of about 70 feet, a maximum depth of 210 feet, and lies at an altitude of 573 feet. The length is 250 miles, the maximum breadth about 58 miles.

Lake Ontario covers an area of 7240 square miles, has a mean depth of about 300 feet, a maximum depth of 738 feet, and lies 247 feet above sea-level. The surface is subject to periodical variations amounting to about 3½ feet. It is 190 miles in length, and 55 miles in maximum breadth.

Lake St Clair, a much smaller lake lying between Lakes Huron and Erie, covers an area of 410 square miles, has an average depth of 15 feet, and lies 570 feet above sea-level; the length is 30 miles, and the maximum breadth 20 miles.

[1] See "Physical Characteristics of the Northern and North-Western Lakes," *Amer. Journ. Sci.*, ser. 3, vol. xxxiii. p. 278, 1887.

[2] See Stanford's *Compendium of Geography: North America*, vol. i. p. 34, London, 1897.

According to Schermerhorn[1] the volume of water in the Great Lakes is about 6000 cubic miles, of which Lake Superior contains somewhat less than one-half. The mean annual rainfall of the St Lawrence basin is about 31 inches, and the mean depth of water evaporated from the surfaces of the lakes between 20 and 30 inches.[2] The amount of precipitation on the water-surface is therefore little more than the amount evaporated from the same area.

The influence of the Laurentian lakes on the climate of their shores is well marked, and was shown as long ago as 1870 by Alex. Winchell.[3] The currents on the lakes have been studied by the United States Weather Bureau by means of bottles containing a record of the locality where they were set adrift, and a request that the finder might note the place where they were recovered and transmit the record to the chief of the Weather Bureau; the results of the observations are published in their bulletins.[4] The general courses of the currents are also indicated on a chart which Russell reproduces on Plate 7 in his *Lakes of North America.* The difference in the currents when the longer axis of the lake coincides with the direction of the prevailing winds, and when it lies athwart that direction, is very clearly indicated.

Between the Great Lakes and the estuary the St Lawrence widens into the following three lakes:—

Lake St Francis, 30 miles S.W. of Montreal, 38 miles long by about 4 miles broad, with an area of 132 square miles, and an average depth of 36 feet.

Lake St Louis, 9 miles S.W. of Montreal, 15 miles long by about 5 miles broad, with an area of 75 square miles, and an average depth of 30 feet.

Lake St Peter, 30 miles long by 7 miles broad, with an area of 200 square miles, and an average depth of 8 feet. The lower end of Lake St Peter is 750 miles from the ocean.

All the great tributaries of the St Lawrence come from the north, as well as many small ones which drain the numerous lakes of the region. Going from west to east, the St Lawrence receives the waters of the following lakes:—

Lake Nepigon, 30 miles N.W. of Lake Superior, 665 feet above sea-level, 70 miles long by 40 miles broad, and with an area of 1450 square miles, and an average depth of over 540 feet, drains to Lake Superior by the Nepigon River.

[1] *Op. cit.*, p. 282.

[2] Thos. Russell, "Depth of Evaporation in the United States," *Monthly Weather Report*, U.S. Signal Office, Sept. 1888.

[3] "The Isothermals of the Lake Region," *Proc. Amer. Assoc.*, vol. xvi. p. 106, 1870.

[4] U.S. Department of Agriculture, Weather Bureau, Bulletin B.

Lake Nepissing, lying at an elevation of 644 feet, drains by French River to Georgian Bay, Lake Huron.

Lake Simcoe, 30 miles long by 18 miles broad, and 300 square miles in area, lies at an altitude of 701 feet, about 130 feet above Georgian Bay, into which it discharges through Lake Couchiching and the River Severn.

Lake Temiscaming is practically the head of the River Ottawa, the largest tributary of the St Lawrence. The name Temiscaming means "deep water," and the lake is said to be very deep, though reliable soundings do not appear to have been made yet in its waters. It is 612 feet above sea-level, 75 miles in length, and from 1 to 5 miles in breadth.

The course of the Ottawa is interrupted by a succession of lakes and rapids, and falls from over 700 feet to about 60 feet above sea-level in drops of 150, 140, and 120 feet. **Lac des Chats**, on its course, is 50 miles long, and **Lake Deschenes** 25 miles long.

Lake St John lies 278 feet above sea-level, about 100 miles N.N.W. of the city of Quebec, and occupies an almost circular basin 28 miles long by 20 miles broad, with an area of 366 square miles. It drains to the St Lawrence estuary by the Saguenay River, the course of which is much interrupted by rapids.

Summit Lake in Labrador has a double outflow, one by the Koksoak River to the north into Hudson's Strait, and the other by the Manicouagan River to the south, joining the St Lawrence west of Point de Monts, after a course interrupted by short reaches of lake and much broken water. It lies on the 53rd parallel of latitude, about 1940 feet above sea-level.

The Fox River flows into Green Bay, an arm of Lake Michigan, and receives the drainage of a large section of the north-eastern part of Wisconsin, an area covered with glacial drift. Connected with the river and its tributaries is a great number of lakes, many of which, although covering areas of considerable size, are merely expansions of the rivers, and are for the most part very shallow, with low, swampy shores. The deeper lakes are Stone Lake, with depths of 75 and 80 feet in its deepest part; the Waupaca Lakes, small in area but with a depth in some cases of 60 to 95 feet; and Green Lake.

Green Lake is a long, narrow body of water, covering an area of 11½ square miles, slightly over 7 miles in length, and less than 2 miles in maximum width, with a maximum depth of 237 feet, and an average depth of over 100 feet. The water of the lake is of a clear green colour, and because of its depth there is a large body of water at the bottom which is never appreciably affected by even the severest storms. The lake has a distinct "thermocline" during the summer months, and the water at the bottom has an annual range of temperature of only about 10 degrees Fahrenheit. Marsh[1] has made a special study of the fauna of this lake, and says that in general character it resembles that of the Great Lakes. Green Lake is taken as a type of a deep lake, and Lake Winnebago, about 25 miles east of it, drained by the Fox River, as a type of a shallow lake.

Lake Winnebago is about 28 miles long, by 8 to 10 miles broad. There has never been an accurate hydrographic survey of the lake, but it is probable that it is nowhere over about 25 feet deep. The water of this lake is very much discoloured during most of the year, and owing to its shallowness storms disturb it to the very bottom over the greater part of its area, with the result that during summer it has a nearly uniform temperature from top to bottom, becomes warmed early in spring, and cools off with corresponding rapidity in autumn.

Lake Champlain.—To the south of the St Lawrence estuary, in the basin between the Adirondacks and the Green Mountains, extending a short distance into Canada, lies the valley of Lake Champlain, the geographical history of which is exceedingly remarkable, for this fresh-water lake was originally a well-developed river valley excavated by a stream tributary to the Greater St Lawrence when the land stood higher than now. After acquiring its present form the Champlain valley was depressed and became an arm of the sea, inhabited by marine molluscs and frequented by whales. A tideway reaching southward connected with the submerged Hudson River valley, thus making New England an island. A partial re-elevation of the land caused the gulf to be separated from the ocean, so as to form a saline lake, the salt waters of which were ultimately flooded out, the rains and feeding streams furnishing a supply of fresh water in excess of the amount lost by evaporation. Elevated strands with recent fossil remains indicate the former great extent of the lake. The lake now drains into the estuary of the St Lawrence by the Richelieu River, and is connected with the Hudson River by the Champlain Canal. The length of Lake Champlain is about 125 miles, its maximum breadth about 15 miles, its area 595 square miles, its greatest depth 600 feet (Emmons), and its height above sea-level 93 feet.

Lake George (sometimes called Horicon), a long and narrow lake of New York, forms part of the boundary between Warren and Washington counties. It lies 325 feet above sea-level, covers an area

[1] See "Limnetic Crustacea of the Great Lakes," *Trans. Wisconsin Acad. Sci., Arts, and Letters*, vol. xi. p. 179, 1897; also "The Plankton of Lake Winnebago and Green Lake," *Wisconsin Geol. and Nat. Hist. Survey*, Bull. No. xii., Scient. Series, No. 3, p. 1, 1903.

of about 50 square miles, being 25 miles in length, with a maximum width of about 3 miles, and discharges into Lake Champlain.

"**Lake on the Mountain**" is situated on the top of a cliff, 180 feet in height, which rises on the south side of the Bay of Quinté, a bay on the northern shore of Lake Ontario. The outflow gives the power which operates the Glenora Mills, but its inflow is invisible and yet steadily maintained from year to year. The lake is 300 feet from the edge of the cliff, and measures three-quarters of a mile in length. The greater part of it is shallow, not exceeding a few feet in depth; but close alongside its southern boundary is a great rent, as it were, in its bottom, nearly a mile long, one-third of a mile or more wide, and varying from 75 to 100 feet deep. Probably the rent has some connection with a widened fault in the Trenton limestone area 25 or 30 miles to the north-east of the Bay of Quinté, and the forces which gave rise to the fault may have caused subterranean communication with higher ground many miles away. The dip of the rocks is favourable, and the whole area into the Laurentian region beyond is a steady rise, till about 50 miles away a height of nearly 400 feet above Lake Ontario is reached. During a period of drought in the neighbourhood the level of the lake was well maintained, so that its source is not attributable to the rainfall in the immediate vicinity. On the other hand, a fair amount of rain fell in the Trenton region during that period, so that evidence seems to point in favour of the waters having their origin there and reaching the lake by an underground channel. In August the temperature of the surface water at the outlet of Lake Ontario opposite Kingston was about 72° Fahr. (22°·2 C.), and at the bottom in 78 feet 56½° Fahr. (13°·6 C.). At the same time in the "Lake on the Mountain" the temperature at the surface was 74¼° Fahr. (23°·5 C.), at 30 feet it was 69½° Fahr. (20°·8 C.), at 45 feet 47° Fahr. (8°·3 C.), at 60 feet 43° Fahr. (6°·1 C.), and at 99 feet 42° Fahr. (5°·6 C.). In the upper 30 feet, therefore, there was little change in the temperature, but between 30 and 45 feet there was a rapid fall amounting to 22½ degrees, and from 45 feet to the bottom a further fall of only 5 degrees.

Rivers Saskatchewan and Nelson.

The geography of the region to the north-west of the Laurentian basin, which now drains to Lake Winnipeg and thence through the Nelson River to Hudson Bay, underwent many revolutions during the advance and retreat of the ice-sheet. The drainage to the north was obstructed, and a lake formed over the country of mild relief surrounding Lake Winnipeg and the Lake of the Woods, and extending southward through the Red River valley far into Minnesota. This lake, now marked by its ancient shore-lines and the deltas of inflowing rivers on the east and west, has been called Lake Agassiz in

Lake Agassiz.

honour of Louis Agassiz, and must have covered an area of about 110,000 square miles, exceeding the combined areas of the present Laurentian lakes. It discharged southward to the Mississippi, and excavated the channel now occupied by Lake Traverse, Big Stone Lake, and the Minnesota River; but as the glacier retreated, and an outlet northward was opened up, the level of the waters was gradually reduced till the lakes of to-day were left in the deepest portions of its basin. This great lake, as measured from its shore-lines, had a diameter from north to south of 675 miles, and from east to west of about 300 miles, and had a drainage area of about half a million square miles. At the site of Lake Winnipeg the ancient lake was 600 feet deep. As with the Laurentian glacial lakes, the shore-lines of Lake Agassiz now rise northward at a slight inclination, proving that an elevation of the land must have taken place during the rise and disappearance of the ice-sheet.

Lake of the Woods is the main hydrographical feature of the country between Lake Superior and Lake Winnipeg, a district studded with lakes and intersected by swift-flowing streams. It is 70 miles long, by 60 miles broad, but its outline is indented to an extraordinary degree, and its northern portion is filled with islands. The Lake of the Woods lies about 1060 feet above sea-level, and the water area is given as 1500 square miles. Its main tributary is Rainy River, which flows from Rainy Lake, and its outflow is by Winnipeg River to Lake Winnipeg; there are many rapids in the course of Winnipeg River, which is about 163 miles long.

Lake Winnipeg is about 700 feet above sea-level, 250 miles long by 60 miles broad, and has an area of about 9000 square miles; its maximum depth is about 90 feet. On the north-west it receives the waters of the Saskatchewan, together with the surplus waters of Lakes Winnipegosis and Manitoba. On the east it receives the Winnipeg, and on the south the Red River and its tributary, the Assiniboine; the Red River carries to Lake Winnipeg the tribute of Lake Traverse, situated on the Minnesota-Dakota boundary, at the southern limit of the country formerly flooded by Lake Agassiz, and drains through narrow channels sunk in the sediments of the former lake. Between the streams there are broad, nearly level inter-stream spaces, forming typical examples of new land-areas, on which shallow ponds form during rainy seasons. Lake Winnipeg discharges northwards by the Nelson River through several small lakes into Hudson Bay.

Lake Manitoba lies 810 feet above sea-level, and is connected with Lake Winnipeg by the Dauphin River and through St Martin's Lake. It is about 120 miles long, from 5 to 30 miles wide, and covers an area of 1850 square miles. It is a shallow lake with low shores, and very swampy at the southern end, the average depth being 12 feet.

Lake Winnipegosis, lying to the north of Lake Manitoba, at an elevation of 828 feet above sea-level, is about 130 miles long, by 20 miles in maximum breadth. It covers an area of 2080 square miles, and has a maximum depth of 38 feet. It is fed by many small streams from the west, and by the overflow of Lake Dauphin (840 feet above sea-level) through Mossy River. The outlet is by the very indirect way of Waterhen River, through Waterhen Lake, to Lake Manitoba. The total area of the lakes in the Winnipeg basin is 13,500 square miles.

River Churchill.

Lake Wollaston, 1300 feet above sea-level, is the ultimate source of the Reindeer River, one of the chief tributaries of the Churchill River. It is about 800 square miles in area, and discharges by two outlets—to the north by the Stone River into the extreme eastern arm of Lake Athabasca, and to the south-east by the Cochrane River into Reindeer Lake.

Reindeer Lake, 1150 feet above sea-level, is 135 miles long, and has an area of 2490 square miles; the Reindeer River carries its overflow to the Churchill River.

River Rupert.

The rivers in Labrador are often like strings of lakes, and divide and unite again in their course, while the lakes frequently discharge in two directions.

Lake Mistassini, 1350 feet above sea-level, the largest lake, is practically two parallel lakes divided by a range of islands in the centre. The western lake is 90 miles long by 13 to 17 miles wide, and the eastern lake is 60 miles long by 5 to 10 miles wide, the greatest depths being 300 to 400 feet. The lake drains by Rupert's River into James Bay.

River Koksoak.

Lake Kaniapiskau, 70 miles long by 20 miles broad, 1850 feet above sea-level, is the source of the Koksoak or South River, which flows into Ungava Bay in Hudson's Strait.

River Mackenzie.

The principal stream in the Arctic drainage area is the Mackenzie River, the catchment basin of which is only separated by a low and uncertain watershed from the Winnipeg basin. The Finlay and the Peace Rivers form the longest of the tributaries, though the Athabasca, rising farther south, is usually regarded as the main upper branch of the river. Lake Athabasca,[1] Great Slave Lake, and Great Bear Lake, three of the largest of the many great bodies of water which lie along the edge of the Laurentian plateau, are tributary to the Mackenzie River.

[1] The figures for the areas of these lakes are taken from the official Atlas of Canada, 1906.

Lesser Slave Lake is a shallow lake, 60 miles long, with an average breadth of 8 miles, draining by the Lesser Slave River into the Athabasca River. It covers an area of about 480 square miles, and is mostly less than 10 feet deep.

Lake Athabasca (or Lake of the Hills), 690 feet above sea-level, is 195 miles long, by 35 miles in maximum breadth, and has an area of about 3000 square miles. No soundings have been made in the lake.

Great Slave Lake is 391 feet above sea-level, and is 300 miles in length, by about 50 miles in breadth. Its area is about 10,000 square miles. No soundings have been made in the lake.

Great Bear Lake, 340 feet above sea-level, is 175 miles long, has an area of 11,200 square miles, and is very irregular in shape. The average depth is 270 feet.

River Mississippi.

Abundant proof is furnished of the existence of the Mississippi River previous to the glacial epoch by the change that occurs in its valley where the southern limit of the ice invasion intersects its course, between the junctions with the Missouri and with the Ohio. South of the glacial boundary the Mississippi flows through an ancient valley which has been filled with alluvium to a depth of one or two hundred feet in its northern part, and to an increasing depth southward. North of the boundary the course of the river is through a narrow, steep-sided valley, and is interrupted by many rapids alternating with places, in the driftless area of Wisconsin and Minnesota, where the valley broadens and displays signs of old age. The waters of the great tributary of the Mississippi, the Missouri, are supplied in part by the hot springs and wonderful geysers of the Yellowstone Park, where the Yellowstone River drains the lake of the same name.

Yellowstone Lake, 7788 feet above sea-level, is about 20 miles in length, by 10 to 15 miles in breadth, the circumference being about 100 miles, and has an area of about 150 square miles. In some places it is said to be over 300 feet in depth, while the average depth is about 30 feet. It was "in blossom" when I visited it in September 1907, the whole surface being at that time covered with masses of green oscillatoriæ. Near the point of exit of the Yellowstone from the lake, at its north end, is a belt of hot springs 3 miles long by ½ mile wide, some of them extending into the lake.

Two-Ocean Pond is a small lake a few miles south of Yellowstone Lake. It is on the summit of the range—on the great continental divide—and has two outlets: one into the Atlantic through the Yellowstone and Missouri Rivers, the other into the Pacific through the Snake River, a branch of the Columbia.

Lake Mendota, in Wisconsin, lies 846 feet above sea-level, and is 15 square miles in area and 84 feet in maximum depth. The town of

Madison stands between this and the smaller Lake Monona, both of which are traversed by the Catfish River, an affluent of the Rock River, which joins the Mississippi a little below Davenport. Lake Mendota is interesting chiefly from the fact that a biological station has been established on its shores, and that observations have been made on the conditions of life and the distribution of carbonic acid in its waters.[1] Excellent bathymetrical maps were published of this and other lakes of Wisconsin by the Wisconsin Geological and Natural History Survey in the years 1899–1901.

The Mississippi has its rise in the small Lake Itasca (lat. 47° N., long. 95° W.), in a morainic region. Its upper course is guided mainly by the irregular deposits of drift over the immature land-surface, and it receives the waters of the countless lakes lying in the depressions in Minnesota and Wisconsin. An indication of the renewed youth of the river is seen in the number of falls and rapids in its course, and in the mode of formation of Lake Pepin, a short distance below St Paul.

Lake Pepin occupies a barrier basin, the result of a lateral stream carrying more detritus into the valley than the main stream can get rid of. As described by G. K. Warren,[2] the excess of material brought down by the Chippeway River to the Mississippi obstructs the main stream so as to cause an expansion of its waters. The lake is shallow from overflowing on to an open valley, and is about 28 miles long by nearly 3 miles wide.

An approximation to the same conditions occurs at the junctions of the Wisconsin and Illinois Rivers with the Mississippi, but in these instances it is only in the low-water stage that the ponding becomes conspicuous.

South-Eastern Missouri affords several examples of lakes formed by local subsidence resulting from earthquakes. In 1811 and 1812 a large area of the Mississippi valley was shaken, and several parts were depressed so as to be submerged to a small depth by river water. **Lake St Mary** is the largest of these submerged tracts, and measures[3] 30 miles in length, by 5 to 7 miles in breadth.

The limestone regions of Kentucky have been hollowed out through successive ages into many caverns by the chemical action of rain-water on the joints of the rocks and by the erosive power of streams. The Mammoth Cave in Kentucky (lat. 37° 14′ N., long. 36° 12′ W.) is from 40 to 300 feet high, and has vast chambers Mammoth Cave of Kentucky.

[1] See E. A. Birge, "Plankton Studies on Lake Mendota," *Trans. Wisconsin Acad. Nat. Sci.* (Madison), vol. x. p. 421, vol. xi. p. 274, 1897–98; "The Respiration of an Inland Lake," *Pop. Sci. Monthly* (New York), vol. lxxii. p. 337, 1908.

[2] *Amer. Journ. Sci.*, Ser. 3, vol. xvi. p. 420, 1878.

[3] Humphreys and Abbott, "Report on the Physics and Hydraulics of the Mississippi," *Professional Papers*, Corps of Engineers, U.S.A., 1861, Plate II.

traversed by subterranean waters communicating ultimately with the Green River, a tributary of the Ohio, by two deep springs. These waters are known by the following names :—The Dead Sea, 100 feet long, bordered by cliffs 60 feet in height; the River Styx, a body of water 40 feet wide by 400 feet long; Lake Lethe, a broad basin enclosed by a wall 90 feet high; and Echo River, which is about three-quarters of a mile long, from 20 to 200 feet wide, and from 10 to 40 feet deep. Whenever there is a flood in Green River, the streams in the cave become a continuous body of water.

The fauna of the Mammoth Cave has been determined by Putnam and Packard[1] and Cope, who have catalogued twenty-eight truly subterranean species, besides those that may be regarded as having migrated from the surface. Blind grasshoppers, blind crayfish (*Cambarus pellucidus*), blind fish (*Amblyopsis spelæus*) are found, and the great antiquity of the cave is shown by the fact than the true subterranean fauna may be regarded as chiefly of Pleistocene origin.

Twin Lakes are situated in the southern part of Lake County, Colorado, on the west side of the valley of the Arkansas River, a tributary of the Mississippi, and are about 9200 feet above sea-level. They lie a short distance below the mouth of Lake Creek Cañon, and the basins which they occupy were doubtless scooped out by the glacier which at one time flowed down this cañon and joined that occupied by the Arkansas River. As the glacier receded, two terminal moraines were formed, one of which maintains the water in Lower Twin Lake, and the other the water in Upper Twin Lake. The lakes are entirely surrounded with morainal detritus, with no bed-rock exposed except for a short distance along the northern shore of the lower lake. The area of the Upper Twin Lake at about midsummer is 474 acres, and that of the Lower Twin Lake 1440 acres. Hayden[2] in 1873 gave the greatest depth as 79 feet in Upper Lake, and 76 feet in Lower Lake. Juday[3] gives 82 feet and 74 feet for the Upper and Lower Lakes respectively; but both size and depth are subject to variation, as the lakes are now used as a storage reservoir by the Twin Lakes Reservoir Company for irrigation purposes. A dam is now maintained in the old outlet, while the present outlet is a canal. The principal affluent is Lake Creek, which flows into the west end of Upper Lake from Lake Creek Cañon. About a dozen other streams of various sizes contribute their supply of water to the lakes.

The lakes, as might be expected from their altitude, have an alpine

[1] Packard and Putnam, *Inhabitants of Mammoth Cave*, 1872.

[2] See "Twin Lakes," *Ann. Rep. U.S. Geol. Surv. Territories for* 1873, pp. 47 and 54, 1874.

[3] See "A Study of Twin Lakes, Colorado," *Bull. Bureau of Fisheries*, vol. xxvi. p. 152, Washington, 1907.

character, and owing to the climatic conditions the water of the lakes never attains a very high temperature. In fact, the lakes are generally covered with ice for a period of about five months each year. For the winter 1902–03 the maximum thickness of ice on the Lower Lake was 34 inches, and on the Upper Lake 28 inches.[1] The days are warm and pleasant in summer, but the temperature falls rapidly after sunset. The nights are very cool, and hoar-frost may be expected every month of the year. Several sets of temperature observations were made on the two lakes during the months of July and August in 1902 and 1903; in general the temperature conditions during summer were found to be similar to those that have been observed in lakes of corresponding size and depth at much lower altitudes. There was an upper stratum of water, or superthermocline region, the temperature of which increased materially during summer; a bottom stratum, or subthermocline, the temperature of which changed very little during summer; and a more or less distinct transition zone or thermocline between these two strata. The thermocline was found to be from 10 to 13 feet thick in these lakes, and the water in the lower portion of it was about 5° C. colder than that in the upper portion. This transition zone was not nearly so pronounced, however, in these lakes in late summer as was found by Juday in lakes in South-Eastern Wisconsin and Northern Indiana, but it agreed very closely with this zone in the latter lakes when their upper stratum of water had a corresponding temperature early in the summer. During these observations westerly winds blew with considerable regularity, beginning usually about 10 a.m. and lasting till late in the afternoon. As a result of this the water of the superthermocline region was kept stirred up, so that its temperature was tolerably uniform. This produced a fairly distinct thermocline. The superthermocline was considerable thicker in the Lower than in the Upper Lake, owing to the fact that the wind was much more effective in disturbing the upper water of the former, because of its much larger size. On 7th August 1903, for instance, this upper stratum was 26 feet thick in the former and only 10 feet thick in the latter. During both summers the temperature of the Lower Lake was somewhat higher than that of the Upper Lake. Most of the affluents flow into the latter, and it was found that the water of all except one was colder than the surface water of the Upper Lake, so that these affluents would help somewhat in keeping down the temperature of this lake.

The transparency of the water varied somewhat. In general a Secchi disk just disappeared from view at a depth of about 18 feet early in July, and the water gradually became more transparent as the season advanced, so that by the middle of August this depth had

[1] See Juday, *op. cit.*, p. 155.

increased to a maximum of 29½ feet. The lower degree of transparency earlier in the season was due to the fact that the snow on the mountains was melting more or less rapidly, and the streams in consequence were swollen and more or less turbid. As summer advanced the streams became smaller and their waters were clear. The maximum transparency of these lakes exceeds by 10 feet that found in the lakes of South-Eastern Wisconsin in 1900, and by 21 feet that found in Winona Lake, Indiana, in 1901.

The Red River, one of the tributaries of the Mississippi in its lower course, furnishes examples of two different kinds of lakes. The head-water streams bring down more detritus than the trunk stream can carry away, and its flood-plain is built up so fast that the smaller tributaries cannot fill up their valleys at the same pace; they are consequently ponded, and many lateral lakes are formed, arranged, as Davis aptly says, like the leaves on a twig. Lakes are also formed on this river by the blocking of streams by timber-rafts, comparable to the "sudds" of the Nile. The rafts form floating islands, and dam the streams so as to cause their waters to spread out in shallow lakes 20 to 30 miles in length, sometimes many square miles in area, and covered with living vegetation.[1]

The Mississippi in its lower course is an old river with a very gentle slope meandering in broad curves through a wide flood-plain. The loops are frequently cut off, and crescent-shaped or "ox-bow" lakes are left. At its mouth the river is rapidly building a low-grade delta (with lakes) out into the Gulf of Mexico.

Lake Pontchartrain, the largest delta basin at the present time, 40 miles long by 25 miles broad, and with a depth of only 27 feet, lies between the Mississippi and the Pearly River. It communicates with Lake Maurepas on the west, and with Lake Borgne on the east.

Lake Borgne, in the same region, is of later origin and is not yet completed. It communicates with the Gulf of Mexico in the east, and is connected with Lake Pontchartrain on the west by the Rigolets Pass, about 10 miles long.

River Columbia.

A great extent of country drained by the Columbia River and its tributary, the Snake River, in Idaho, Oregon, and Washington, is built up of vast lava-sheets which have converted a broad depression between the Rocky and the Cascade Mountains into an extensive plateau, the great plain of Columbia. These lava-sheets formed great dams across the valleys, and the marshes round the edges of the Snake River lava-sheets seem to be lakes formerly retained by lava barriers but now verging on extinction. The Columbia now skirts the

[1] Chas. Lyell, *Principles of Geology*, 11th ed., vol. i. p. 441; Humphreys and Abbott, *op. cit.*, p. 37.

northern and western borders of the great plain, but in the glacial period, when its present course was obstructed by ice-streams that descended from the mountains on the north and west, it was forced to cut across the plain through a series of deep cañons in the lava. The valleys formed by the river and its tributaries at that time, now nearly dry, are known as "coulées," and the main valley as the "Grand Coulée." The latter is broken at one place by the cliffs of a former cataract, that must have greatly exceeded Niagara in height and breadth. Rapids and cataracts form depressions at their bases, where excavation is accelerated by the friction of the sand and stones moved by the swift current on their bottom and sides. If the stream channel in which such inequalities have been produced be abandoned as a line of drainage, the basins are transformed into lakes retained in part by the barrier formed by the load deposited by the stream waters when the current slackened, some distance below the falls and rapids. Two such lakes exist in the Grand Coulée, each about one mile long by half a mile broad, and of considerable depth.[1] When fractures of the earth's crust occur, the edges of the broken strata on one side are sometimes elevated and those on the opposite side depressed. In some cases lake-basins are produced at these faults, but in others, numerous examples of which are seen in the courses of the Columbia and Yackima Rivers, the edges of the fault blocks have been upheaved so slowly across the streams that the waters have maintained their course and cut a channel through the obstructions as they were elevated, thus preventing the formation of lakes.

The drainage of one of the "coulées" has been obstructed by immense sand-dunes formed by drifting sand, which frequently travels across the country for a score of miles in the direction of the prevailing winds, and the dam so formed retains the waters of **Moses Lake.**[2] Below the dam are several springs, which serve to keep the waters of the lake fresh, and, fed by lake-waters percolating through the obstruction, combine to form Alkali Creek, which in winter sometimes has sufficient volume to reach the Columbia, but in summer suffers from evaporation and terminates in a series of alkaline pools.

Lake Chelan, in the Cascade range, draining to the Columbia by a river about 2 miles long, is a narrow, river-like sheet of water with windings extending westward from the Columbia 70 miles into the mountains, bordered on either hand by a continuous series of rugged peaks that rise from 5000 to over 7000 feet above its surface. The deep, narrow, trench-like valley, now partially filled with water, continues beyond the head of the lake for a distance of about 25

[1] See I. C. Russell, "Geological Reconnaissance in Central Washington," *Bull. U.S. Geol. Surv.*, No. 108, p. 90, 1893.

[2] See I. C. Russell, *op. cit.*, p. 90.

miles into the highlands, thus reaching in total length about 100 miles, and the width of the valley at the level of the lake is only about 4 miles. The lake is over 1100 feet deep, for in several soundings at that depth Russell found no bottom; the surface is only 950 feet above the sea, so that the bottom of the trough is many feet below sea-level. The lake has no beach, and there is scarcely a trace on the rocks, except at the eastern end, to show that it has altered its level, so that it must be of comparatively recent origin, and appears to date from the glacial invasion already mentioned. The valley was not, however, cut by the glacier which occupied it, but is a stream-worn channel, and must at a still earlier period in the earth's history have been excavated in the hard granite by the action of water.

River San Joaquin.

Tulare Lake, in the southern part of the valley of California, is formed by the King River ponding back the upper streams of the San Joaquin River. The river system is youthful, and the lateral stream, gnawing into a lofty slope, sweeps down with it more waste than the main stream can carry away. The surplus accumulates as a fan-shaped delta, and dams back the water, forming a shallow lake with indefinite marshy shores much overgrown with reeds (Spanish *tules*). It was formerly nearly 50 miles in length, but is now practically dry as a result of the withdrawal for irrigation purposes of the waters of King and Kern Rivers formerly discharging into it.

Mexico.

Lake Chapala, the largest lake in Mexico, is traversed by the Rio Lerma, or Rio Grande de Santiago, which flows into the Pacific north of San Blas. The lake is in a manner an expansion of the river, covering an area of about 1300 square miles, and the maximum depth is 98 feet. It is about 80 miles in length by 20 miles in width, but fluctuates with the dry and wet seasons.

The other important lakes of Mexico are connected with inland drainage areas, and have been described under that heading.

Central America.

Lakes Nicaragua and Managua both lie in a depression in the west of the State of Nicaragua, separated from the Pacific by the continental divide from 12 to about 30 miles in width. The overflow from Lake Managua, the smaller and more northerly of the two, is carried into Lake Nicaragua, and thence by the San Juan into the Caribbean Sea at Greytown. Lake Nicaragua has an area of about 4400 square miles, is about 110 miles in length by about 40 miles in average breadth, with a maximum depth of about 150 feet, and its surface varies from 110 feet to 97 feet above sea-level. The lake contains several islands, some of which show monuments of an old civilisation, and one—the island of Omotepe—is an active volcano. A ship-canal from sea to sea, by way of the San Juan River and Lake Nicaragua, was commenced in 1889 by a United States company, but the work was suspended when the United States Government took up the Panama Canal scheme. Lake Managua is 40 miles in length by 25 miles in maximum breadth, with an area of approximately 500 square miles and a maximum depth of about 90 feet. The temperature of the water taken in March 1906 at several points at a depth of 12 feet was 83° F. (28°·3 C.). The same temperature was observed at the northern end of Lake Nicaragua in 18 feet of water.

The fish fauna of these lakes is rather poor considering their size, and comprises about 30 species of true fresh-water fishes, the majority of which are endemic.[1] The presence of marine fishes in the lakes is interesting; with one or two possible exceptions, these are all shore fishes of the Atlantic coast, such as run up all suitable rivers. Mr Tate Regan informs me in a letter that the marine element is a modern one, and does not in any way indicate that the lakes were formerly marine, but only that they were recently accessible from the sea. One of the peculiar ichthyic features of Lake Nicaragua is the red, or partially red, cichlids or mojarras.

South America.

During the glacial epoch a fairly warm temperature must have prevailed in inter-tropical South America, so that the running waters suffered no serious arrest, and the rivers, except in the sub-Antarctic lands of the extreme south, where indications of former glaciation on a vast scale are still in evidence, have excavated their beds down to their natural levels, drained most of the old lacustrine basins, and effaced the greater number of the falls and rapids which formerly abounded in many districts.

The continent of South America was in former geological periods probably occupied by an inland sea surrounded by elevated masses of land. The eastern portion (the Brazilian highlands) was very much higher than the western (the Andean chain), and as the latter gradually rose, and the former was lowered by subsidence and denudation, the sea was broken into two or three secondary basins, the northern portions becoming transformed into the fluvial valleys which now constitute the Orinoco and Amazon systems, and the southern into the valley now traversed by the Parana-Paraguay River and its tributaries. This appears to be the explanation of the intercommunications between the river systems; the Orinoco is linked to the Amazon by the Cassequiare, and the Amazon to the Parana by an intricate network of channels. The slopes of the divide in the latter case are so gently inclined that the slightest cause suffices to divert the currents from one basin to the other. "Due to their horizontality, all the plains, from the

[1] *Biologia Centrali Americana: Pisces*, by C. Tate Regan, London, 1906–8.

mouth of the Mamoré to the Pilcomayo" (that is, right across the main Amazon-Parana divide), "are inundated from October to March, and present the aspect of a great ocean studded with green islands. . . . Across the Monde Grande, a simply overturned tree would change the course of the waters."[1]

Lake of Maracaibo is a marine inlet, the largest in South America, 137 miles long by 75 miles broad, 9000 square miles in area, but it is rather of the nature of a lake or lagoon than of a gulf, being so entirely landlocked that the tides are scarcely felt a little way inside the bar. Beyond the bar the waters are quite fresh, the supplies received from the surrounding streams being greatly in excess of the marine currents. The greatest depth is 500 feet, but the stream deposits are slowly filling up the inlet.

Lake of Valencia, in Venezuela, 22 miles broad and 300 feet in maximum depth, which fills a great part of the rich Aragua valley, is one of the most remarkable sheets of water in the world, for, although it seems completely encircled by the coast and inland ranges, it has two different outlets, on the western shore close to the city of Valencia, by one of which it has occasionally sent its overflow through the Trincheràs northwards to the Agua Caliente, an affluent of the Caribbean Sea, and by the other it has communicated several times through the Paito southwards with the Pao, a tributary of the Orinoco. According to the oscillations of level the southern emissary has thus been alternately an affluent and an effluent. The water had been steadily subsiding for some years before 1882, but since that time the lake appears to be rising to its former high level when it discharged into the Orinoco; the waters of the lake have become slightly brackish.

The lakes situated along the Great Andes in Chili and Patagonia are numerous. In Chili, south of Arauco, there are many lakes, all regarded as being very deep, although few trustworthy soundings have yet been carried out.

Lake Nahuelhuapi, in Patagonia, 2000 feet above sea-level, the source of one of the head-streams of the Rio Negro, is about 40 miles long, with an extreme breadth of 9 or 10 miles.

Lake Buenos Ayres, in Patagonia, about 50 miles long by about 12 miles broad, presents a very remarkable hydrographic feature.[2] The lake draws most of its waters from the northern glaciers by means of a fairly large river called the Fenix. For about 30 miles

[1] Castlenau, quoted by G. E. Church, "Argentine Geography and the Ancient Pampean Sea," *Geogr. Journ.*, vol. xii. p. 389, 1898.

[2] See J. W. Evans, "Hydrography of the Andes," *Geogr. Journ.*, vol. xxv. p. 71, 1905.

this river holds its own as an important stream, until it divides into two channels, one flowing into the lake and through it to the Pacific, and the other to the Atlantic.

Lake Argentino, in Patagonia, stretching east and west, is about 60 miles long, and from 10 to 20 miles broad. The western end has several arms penetrating deep into the recesses of the cordillera, and there receiving the water of numerous glaciers. Large icebergs are to be seen floating on the lake with the prevailing westerly wind. Lake Argentino receives the drainage from Lake Viedma, and the outflow is by the River Santa Cruz into the Atlantic. A low range of mountains separates Lake Viedma from Lake San Martin, which has an exit into the Pacific.

Lake San Martin occupies what was once a strait joining the Atlantic and Pacific. The main body of the water runs almost east and west, penetrating into the heart of the cordillera. The mountains rise abruptly from its shores, and it is subject to the most violent storms. Captain H. L. Crosthwait[1] made observations of seiches on the lake.

Laguna Tar.—At the east end of the San Martin valley is a small shallow lake called Laguna Tar. Crosthwait says that at present its waters flow into Lake San Martin (that is, in a westerly direction), but that the continental water-divide is here so ill-defined that a cutting of a few feet would cause Laguna Tar to flow to the Atlantic. The dry bed of a stream is visible, and in time of flood this lake may, temporarily, have an exit in both directions.

AUSTRALIA.

No lakes of any importance are connected with the rivers of Australia which drain to the sea.

TASMANIA.

Several large lakes in the centre of Tasmania, nearly 4000 feet above sea-level, including the Great Lake, Lakes Sorell and Echo, drain by various tributaries into the River Derwent. The Great Lake, 3800 feet above the sea, is the largest, being about 12 miles long by 4 miles wide. The Derwent River takes its rise in Lake St Clair.

NEW ZEALAND.[2]

The Waikato River is the largest in North Island, New Zealand, and, rising about lat. 39° S., drains Lakes Taupo, Waikare, and Whangape on its course to the sea.

[1] See "A Journey to Lake San Martin, Patagonia," *Geogr. Journ.*, vol. xxv. p. 286, 1905.

[2] The lakes of New Zealand were surveyed by Keith Lucas in 1902; the particulars are abstracted from his report in the *Geogr. Journ.*, vol. xxiii. pp. 645 and 744, 1904.

Lake Taupo extends from lat. 38° 40′ to 38° 57′ S., and from long. 175° 46′ to 176° 6′ E., lying 1211 feet above the sea. It has an area of about 238 square miles; its length is 25 miles from north-east to south-west, its greatest breadth 16½ miles, and its mean breadth, at right angles to the long axis, 9½ miles. The lake is roughly divided into three portions: (1) the southern end, the greater part of which is included between the 300 and 360-feet contours; (2) the western bay, which lies chiefly between the 360 and 420-feet contours; and (3) the north-east portion, which includes the maximun depth of 534 feet. The mean depth is 367 feet. The hot springs of Tokaanu and of Waipahihi pour their waters into this lake.

At about 45 miles from its mouth, and shortly after its junction with the Waipu, the river breaks through a chain of low hills and enters a broad plain, in its course through which it is flanked on either side by a series of shallow lakes—Waikare and Kimihia on the east, and Whangape, Roto Ngaro, and Wahi on the west.

Lake Waikare, about 11 square miles in area, is separated from the Waikato River by a strip of low land, from which projects a peninsula dividing the lake into a larger north and a smaller south basin, leaving a channel one mile wide between them. The depth over the greater part of the lake is from 8 to 9 feet. A hot spring rises from the bed of the lake, in a small depression including the maximum depth of 12 feet; and two streams, the Te Onetea and the Rangiriri, serve as outlets for the waters of the lake when the Waikato is low, but a rise in the level of the river is sufficient to reverse the current in them. In this way the Waikato serves as the chief source of water for the lake in certain seasons. As the Rangiriri joins the river at a lower level than the Te Onetea, the former may serve as an inlet while the latter is serving as an outlet. Lake Waikare reduces the harmful action of floods on the Waikato River.

Lake Whangape lies to the north-west side of the plain through which the Waikato runs, and drains to it by a small stream. Its length is 5¼ miles, its greatest breadth a little more than 2 miles, and its area about 4 square miles. A narrow channel a quarter of a mile broad divides a larger north from a smaller south basin. The greater part of the lake-floor is included within the 8-feet contour, the maximum depth being 9 feet.

Lake Tarawera is about 9 miles long and 6½ miles broad, and drains by the Tarawera Creek to the Matata River, and thence to the Bay of Plenty. The temporary damming of the outlet from Lake Tarawera, and the subsequent breaking down of the barrier, will be referred to in the description of the Great Tarawera Volcanic Rift.[1]

[1] See p. 647.

North and north-westward from Lake Tarawera lies a rugged volcanic country dotted with numerous lakes, the largest being Lake Rotorua. These lakes, called the "Hot Lakes" of New Zealand, because their shores are marked by geysers and hot springs, appear to fill depressions formed by the down-faulting of limited areas in a lava plateau which formerly existed, but is now represented by the flat volcanic hills bordering the lakes. These lakes drain to the Bay of Plenty.

Lake Rotorua, 915 feet above sea-level, covers an area of about 32 square miles, and consists of a roughly circular basin 6 miles in diameter, broken by an irregular southern extension, which increases the length in a north-and-south direction to a maximum of 7½ miles; the mean breadth is about 4 miles. The deepest sounding taken in the lake was 120 feet, in a hole probably not more than a chain across near the southern shore, the average depth being 39 feet. The lake is fed by several streams and a great number of springs, many of which are hot. The hot springs occur in two main groups, one north-east of the lake, and the other on its southern shore. The springs of the latter group are close to the waters' edge or actually in the lake, and where the water is shallow the presence of springs at the bottom is shown by the milkiness of the water, due to sulphur held in suspension. The south end of the lake is marked by great thermal activity. The outlet is by the Ohau stream, which, after crossing a belt of low-lying flat land little more than half a mile in width, enters the west end of Lake Rotoiti.

Lake Rotoiti, 910 feet above the sea, covers an area of about 14 square miles; its length is nearly 11 miles, its breadth from 1 to 2 miles, its greatest depth 230 feet, and its mean depth 69 feet. The lake is divided by a narrow channel into a large eastern and a small western basin. The outlet is by the Okere or Kaituna River.

Lakes Waikaremoana and **Wairaumoana** lie at the southern border of Tuhoe Land, 2015 feet above sea-level, 25 miles from the sea-coast of Hawke Bay, to which they drain by the Wairoa River. The land between the lakes and the sea-coast is intersected by irregular ranges of hills, increasing in height as the lakes are approached. The valley occupied by the main body of the lakes runs parallel to the Panekiri range for a distance of 7¼ miles measured in a straight line. Two arms run out from this valley from its opposite sides, about midway between its extreme ends, one towards the south, leading to the outlet of the lakes at Onepoto, the other formed by the Whanganui and Mokau inlets. The greater part of the lakes, therefore, has the form of a cross, the axes of which measure 7¼ and 6¼ miles in length, and to that part the name Lake Waikaremoana strictly applies. The remainder is a narrow valley, 5½ miles long, directed approximately north-east and south-west, called Lake Wairaumoana, which is connected to Lake Waikaremoana by a passage half a mile in width, known as the Straits of Manaia. The area of Lake Waikaremoana is about 15 square miles, and of Lake Wairaumoana about 6 square miles. The greatest depth recorded in the whole lake is one of 846 feet in Lake Waikaremoana, and occurs within a depression having an area of 1·3 square miles exceeding 800 feet in depth. The deepest sounding taken in Lake Wairaumoana is 375 feet. The mean depth of Lake Waikaremoana is 397 feet, or 47 per cent. of the maximum depth; the mean depth of Lake Wairaumoana is 175 feet, or 49 per cent. Lucas considers these lakes a system of radiating valleys, having the deepest part at the point where all the valleys meet.

Lake Wakatipu is drained by the Kawarau River, a tributary of the Clutha River, in South Island, and lies at a height of 1016 feet above sea-level, extending from lat. 44° 50′ to 45° 20′ S., and from long. 168° 20′ to 168° 43′ E. The two ends of the lake trend in a direction almost north and south, but the middle part runs nearly east and west. The length is 49 miles, the greatest breadth about 3 miles, and the area exceeds 112 square miles. The maximum depth obtained by Lucas was 1242 feet; the volume of water is 15 cubic miles, and the mean depth 707 feet. The lake appears to be a mountain valley filled with water.

The Clutha River takes its rise in the two lakes **Wanaka** (area 75 square miles) and **Hawea** (area 48 square miles), in which maximum depths of 1085 and 1285 feet respectively have been reported.

Lake Manapouri, 597 feet above the sea, extends from lat. 45° 27′ to 45° 35′ S., and from long. 167° 28′ to 167° 40′ E. It is very complicated in outline, and covers an area of about 56 square miles. The greatest depth, 1458 feet, occurred within a large depression about 2½ square miles in area, which exceeds 1400 feet in depth, the mean depth being 328 feet. The surface of the water lies at approximately 597 feet above sea-level. The lake receives from the north the surplus waters of **Lake Te Anau** (36 miles in length and 1 to 6 miles in breath), and drains south by the Waiau into the South Pacific Ocean.

CRATER LAKES

Crater lakes would appear to constitute a class by themselves, since they are not directly connected with river drainage, and are to a very small extent influenced by climatic oscillations. They occupv the hollows in the summits of the cones of dormant volcanoes, and the basins, called "calderas," which are formed when a volcanic cone is destroyed by a violent explosion, or is undermined by the liquid lava in the core of a mountain.

Lake of Laach, near the Rhine below Coblenz, lies at an altitude of 750 feet in the Eifel, one of the regions of recently extinct volcanic action in Europe. It is an oval cavity, $1\frac{1}{4}$ square miles in area, with a maximum diameter of $1\frac{1}{2}$ miles, a maximum depth of 174 feet, and a mean depth of 107 feet. It has been made to drain by an artificial cut into the River Nette, a short tributary of the Rhine, below the Mosel. The surface of the surrounding country is strewn with fragments from the hollow, but they do not form a distinct crater-wall enclosing it. The water has a disagreeable taste, and never freezes. EUROPE.

Lake Lonar is situated on the trap-plateau of the Deccan in India. It is a shallow salt pool at the bottom of a cavity about a mile in diameter, and three or four hundred feet deep. On the north and north-east sides the edge of the hollow is on a level with the surrounding country; elsewhere there is a rim of blocks of trap, 40 to 100 feet high. The volume of the rim is, however, only about a thousandth part of the cavity, and no lava-flow from it can be detected on the surrounding surface, so that it must owe its existence in part to the effect of subsidence. ASIA.

Three lakes, separated by narrow walls, occupy the great crater of the Shiranesan of Kusatsu, Northern Japan. The sides of the cone, as well as the lake-basins, are composed of grey tuff and sulphur, through which in places andesitic rocks crop out in the bold cliffs and pinnacles. The crater is oval and nearly half a mile in length, but the lakes are circular. The central lake-basin, the water of which is boiling in the north-western part, is a quarter of a mile in diameter, but all the lakes appear to be diminishing in size.[1] The crater of Azuma, in the same region, is also occupied by a lake a quarter of a mile in diameter.

North of Lake Nyasa, in a hollow between two ranges of mountains, lies a series of seven volcanic lakes[2] surrounded by extinct volcanoes, cinder beds, and hot springs:— AFRICA.

[1] C. E. B. Mitford, "Notes on the Physiography of Certain Volcanoes in Northern Japan," *Geogr. Journ.*, vol. xxxi. p. 198, 1908.

[2] See D. Kerr-Cross, "Crater Lakes north of Lake Nyassa," *Geogr. Journ.*, vol. v. p. 112, 1895.

Lakes Kingire and **Ikapa** are said to be about 500 yards in diameter, and abound in fish.

Lake Kiunguvuvu, about two-thirds of a mile in diameter, is situated in a very large volcanic cone. It has no visible outlet, but since several streams rise on the side of the cone, the water probably finds some underground exit.

Lakes Itende and **Itamba** are smaller lakes in the vicinity of Kiunguvuvu.

Lake Kisiwa is about one square mile in area, and as the cone is less defined it is probably older than the others.

Lake Wutiva lies in a hollow in Mount Rungwe, two-thirds of a mile in diameter. It contains little water, the surface of which is about 1500 feet below the rim of the crater. Several springs were observed in the sides of the crater, but the lake has no visible outlet.

AMERICA. **Crater Lake** in Oregon is situated in Cascade Range, at 6239 feet above sea-level. It is oval in shape, about 21 square miles in area, and is surrounded by cliffs ranging from 500 to nearly 2000 feet in height. The lake is nearly 2000 feet deep in places, and near its western margin contains a rocky island, evidently a former volcanic vent. It occupies the bowl of a volcanic cone, which must have risen some 6000 feet above the rim of the present lake. The entire summit sank owing to its being undermined by the liquid lava in the core of the mountain.

Boiling Lake of Dominica was only discovered in 1875 through the accident of a man's losing his way in the forests of Dominica. It lies in a volcanic centre called Grande Soufrière, the area of which is about 5 square miles, at an elevation of 2425 feet above the sea. The lake is elliptical in form, measures about 200 feet by 100 feet when full, and drains intermittently into the Pointe Mulâtre stream. Vertical cliffs rise from the water, and no bottom was found in sounding 10 feet from the edge at 195 feet. It is wholly different in character from the ordinary geyser. Its waters do not rise in fountain form but merely become ebullient, remaining so for days, while at other times it is quiescent—but still a lake, not a funnel. It is not yet known whether ebullition occurs at definite periods. Sulphuretted hydrogen is intermittently exhaled, and proved fatal to a visitor and guide in 1901, while other visitors have suffered from its effects.

The crater of the **Soufrière** in St Vincent is occupied by a lake. Prior to May 1902, when the last eruption of the volcano took place, the Soufrière was noted for its beautiful lake of green water. Mr P. F. Huggins[1] took soundings in the years between 1896 and 1900,

[1] See *An Account of the Eruptions of the St Vincent Soufrière*, St Vincent, 1902.

and found a depth of 525 feet in the middle of the lake. This deep lake was thrown out by the 1902 eruption, and its place taken by a shallow pool of brown muddy water, while the walls were completely denuded of the vegetation which had previously covered them. For about two years the pool was troubled with gentle puffs of steam, or was thrown out and destroyed by strong eruptions, but now the crater is perfectly quiet, and the lake has regained much of its former size and depth. The water is a beautiful yellowish green colour, and the walls give various tones of red, purple, and grey, producing a marvellous setting to the green lake. The surface of the water is about 2000 feet below the rim of the crater, which is about 3013 feet above sea-level.[1]

Lake of Atitlan, in Guatemala, is 24 miles in length by 10 miles in breadth. There are several large volcanoes on its south bank; on the east, north, and west, where there are no volcanoes, the slopes are very steep and much cut up by valleys of rivers and small streams flowing into the lake. It has been supposed that the basin of the lake is only a continuation and union of these valleys, and that, after they had been excavated, the volcanoes broke out on their beds and formed the lake by blocking the exit for the water. On the other hand, the west shore of the lake extends in a well-marked, almost precipitous bank right round to the south of the volcanoes of San Pedro and Atitlan, and is perfectly separate from the slopes of San Pedro, and to a large extent from those of Atitlan; it is composed of beds of tuff, all dipping to the south towards the Pacific and away from the lake. This seems to show that it is the lip of an enormous crater, and that the volcanoes of San Pedro, Atitlan, and Toliman, giants as they are, are merely secondary cones thrown up on its floor. If that is so, this crater must certainly be one of the largest, if not the largest, in the world.[2]

NEW ZEALAND.

The great Tarawera volcanic rift in North Island, New Zealand, was formed at the time of the great eruption of Mount Tarawera on 10th June 1886, and stretches from Mount Wahanga, the most northerly point of the Tarawera range, to about 600 yards north-west of Lake Okaro. The length of this huge fissure is about 9 miles, and though practically continuous, it is divided by low partitions into several somewhat distinct craters. As a result of the eruption streams were dammed and temporary lakes formed. The bed of Tarawera Creek, which drains Lake Tarawera, was filled up, and

[1] See E. O. Hovey, "Camping on the Soufrière of St Vincent," *Bull. Amer. Geogr. Soc.*, vol. xli. p. 72, 1909.

[2] See Tempest Anderson, "The Volcanoes of Guatemala," *Geogr. Journ.*, vol. xxxi. p. 482, 1908.

the lake immediately started to rise. For years some of the water found exit through cracks in the tuff filling the creek bed, but when the lake had risen 42 feet the water flowed over the dam of tuff which prevented its exit along the old channel and broke much of it away, so that the level is now 11 feet below its maximum. Low cliffs marking the former level of the lake testify to the changes which its surface has undergone. Maclaren, of the Geological Survey of India, expresses a doubt as to the correctness of the views of Suess [1] regarding the necessarily deep-seated origin of geyser water, and contends that such waters may be of quite superficial origin, quoting the instance of the Waimangu geyser in support of his theory.[2] This great geyser, discovered in 1900, which remained in active eruption for over four years, became dormant on 31st October and 1st November 1904, the very days on which the pent-up waters of Tarawera Lake overtopped their barrier.

Lake Rotomahana lies south-west of the Tarawera range, in about lat. 38° 20′ S., and occupies the site of an immense crater, which was apparently the most active point of the Tarawera eruption in 1886, when the exquisite siliceous pink and white terraces were destroyed. Immediately after the great outburst there was comparatively little water distributed in a number of small ponds in the huge hole, but with no outlet. The water gradually rose, and to-day is still rising, though much of the water entering the lake must find some subterranean outlet. It is a sheet of dirty, muddy, green water some 3½ miles long by less than 2 miles broad, and with a maximum depth of 427 feet. The boundaries of the lake correspond with the walls of the crater. Thermal action is at present limited to the western end of the lake, where, however, there is abundant evidence of the proximity of a heated interior in the great columns of steam ascending from the cracks in the stratified tuff beds. A warm stream enters the south-western end of Lake Rotomahana, formed by the junction of two steaming cascades which flow from the craters of Inferno and Waimangu.

The temperature of the lake in the Inferno crater is about 180° Fahr. (82° C.), and its surface is rather less than 2 acres in extent. It emits almost continually steam charged with hydrogen sulphide.

In 1899 Echo Lake crater contained a lake almost a quarter of a mile in diameter, which has now diminished to a small pond a few yards across, lying at the base of a cliff of variegated tuff. The floor of the remainder of the crater is formed by a surface of tuff hardened mainly by silica, but partly by incrustations of alum; through this

[1] Suess, "Hot Springs and Volcanic Phenomena," *Geogr. Journ.*, vol. xx. p. 518, 1902.

[2] *Geol. Mag.*, ser. 5, vol. iii. p. 511, 1906.

crust spout innumerable small jets of boiling water. This flat is known as the "Frying Pan."

The Southern Crater, the most south-westerly of all the craters along the line of the great rift, lies about 200 yards south-west of the "Frying Pan." Like most of the other craters, it is bordered by precipitous walls. It is filled by a pond of greenish water 50 or 60 yards across by 100 yards in length, and 60 or 80 feet deep. Some years ago the crater was quite dry. Unlike the other craters, it shows no sign of thermal activity.

ANTARCTIC LAKES [1]

At Cape Royds on Ross Island (latitude about 77° 30′ S.) the British Antarctic Expedition, 1907–9, found many small lakes occupying rock-basins. The smaller ones melted in summer, but those over 5 feet in depth did not even partially melt in the two summers when they were under observation. A few soundings were made by digging shafts in the ice. The deepest sounded—Blue Lake—had 5 feet of water under 21 feet of ice. In another place Blue Lake was frozen to the bottom (at 15 feet). The bed was of gravel in angular pieces, covered with a thin film of yellowish vegetation. Coast Lake, about 4 feet deep, had a thick layer of a soft peaty deposit. Few of these lakes had any overflow to the sea. One lake, separated from the sea only by a broad stretch of flat gravelly beach, had its surface 18 feet below sea-level.

Vegetation, in the form of broad, lichen-like sheets of an orange-coloured plant, covered the beds of the lakes, and on it were myriads of microscopic animals. These animals (Rotifers, etc.) showed themselves capable of living in the adult condition frozen in the ice for a number of years. There were few plankton organisms in the open water, nothing being seen but some blue-green Algæ (Oscillatoria, etc.), some Infusoria, and a Rotifer (in one lake only).

SUMMARY

The foregoing review of the principal lakes and lake-regions of the world is necessarily incomplete and fragmentary: at the present time our knowledge of the physical and biological conditions in many of these lakes is very meagre, but is rapidly extending in all directions. We may look forward to interesting additions to the science of

[1] See notes by James Murray in Shackleton, *The Heart of the Antarctic*, London, 1909.

limnography in the near future, which will have an important influence on our conceptions as to the past history of the earth and its fauna and flora.

In all, about 250 lakes have been referred to and briefly described. About 60 of these are situated in inland drainage areas, and the remaining 190 lakes are situated in the areas which drain directly to the ocean. The area covered by the 60 lakes of the inland drainage areas is just about the same as that of the 190 lakes draining directly to the ocean, namely 300,000 square English miles for each. This arises from the great size of the Caspian Sea, which is situated in the inland drainage area of the Eural-Asian continent. It is difficult to estimate even approximately the area covered by all the lakes and rivers of the world, but it may be taken as not less than 1,000,000 square English miles, or about $\frac{1}{55}$ of the land-surface.

The most abundant development of lakes at the present time is found in those regions which have in recent geological times been covered by an ice-sheet. As examples may be cited the lakes situated towards the head-waters of the rivers St Lawrence, Churchill, Nelson, and Mississippi in America, and the Rhine, the Rhone, and the Po in Europe. On the other hand, some of the greatest river-basins in the world contain very few lakes, and none of great dimensions. The Amazon and the Orinoco in South America, the Indus and Ganges in Asia, the Niger and Orange Rivers in Africa, may be mentioned in this connection. In Eastern Africa there are numerous lakes towards the head-waters of the Congo, the Zambesi, and the Nile, and there is no evidence of glaciation in the region. Here the basins appear to have been formed by earth-warping and volcanic action in recent geological times.

A detailed study of the phenomena now exhibited at the surface of the solid crust of the earth is the surest method of obtaining knowledge for the correct interpretation of the conditions under which the various geological formations of past ages were laid down. In the present state of our knowledge, five distinct regions appear to be indicated, each of which has its own individual characteristics, although it must be admitted that on the border-lines between these different areas the interpretation of the phenomena may be difficult and uncertain.

I. **The Region of Inland Drainage Areas.**—This is estimated to cover 11,000,000 square English miles of the continents, or about 20 per cent. of the land-surfaces and $5\frac{1}{2}$ per cent. of the whole surface of the globe. The rainfall is usually less than 10 inches per annum. The sand, gravel, and fine dust derived from the disintegration of the rocks are distributed by winds and water in a manner not observed in other regions, and these fragments often bear the marks of their origin. Vegetable and animal remains are never abundant. Great sandstone beds are always in process of formation. The lake-deposits, so far as yet examined, present peculiarities which can be detected by the microscope, and are largely composed of sandy particles, even when mixed up with salt deposited from the salt lakes. There is very little or no organic deposit of calcium carbonate.

II. **The Region of Lakes and Rivers draining directly to the Ocean.**—This covers about 44,000,000 square English miles, or about 80 per cent. of the land-surfaces and $22\frac{1}{2}$ per cent. of the whole surface of the globe. The rainfall is most abundant, and so also is vegetable life. Coal and lignite beds have been laid down in this region in past ages, and in all the clays, muds, and marls there is usually a large admixture of terrestrial organic remains. Lakes are not numerous except in places where there has been recent glaciation and earth movements. The deposits in the lakes can, on examination, usually be distinguished from those formed in inland drainage areas. They do not contain any salt deposits, and the aspect of the sandy particles is different.

III. **The Littoral and Shallow-Water Region.**—This region of the ocean, from high-water mark down to a depth of 600 feet, covers about 10,000,000 square English miles, or 7 per cent. of the water-surface and 5 per cent. of the entire surface of the globe. The formations in this region consist of the most varied material derived from the land-surfaces and mixed up with the calcareous and siliceous materials which have been secreted from the ocean by organisms. These consist of boulders, shingles, sands, marls, muds, clays, coral reefs, and other calcareous deposits secreted by benthonic animals and plants. The action of waves and currents is nearly always to be detected. Indeed, the geologist recognises the marks of formations laid down in this area more distinctly and more frequently than those of any other region, although its area is the smallest of the five great divisions.

IV. **The Region of Deep-Sea Terrigenous Deposits.**—This area lies between a depth of 100 fathoms and the greatest depths within 200 miles from continental land, embracing all partially enclosed seas. It covers an area of 33,000,000 English square miles of the sea-floor, or $23\frac{1}{2}$ per cent. of the water-surface and 17 per cent. of the entire surface of the globe. It is essentially the area of muds and marls, with which are mixed the remains of both plankton and benthonic organisms. Quartz grains are abundant in the deposits, and glauconite and phosphatic nodules are quite characteristic of the area. Chalks and Radiolarian cherts were laid down in this region.

V. **The Abysmal or Pelagic Region of the Ocean.**—This embraces the whole floor of the ocean beyond 200 miles from continental shores and deeper than 1400 fathoms—the mean sphere level. It covers 98,000,000 of square English miles, or 69½ per cent. of the water-surface and 50 per cent. of the entire surface of the globe. Sunlight never penetrates to this area. The temperature is not far removed from 0° C. (32° Fahr.), and evidences of erosion or transport are absent. The deposits consist of red clays and organic oozes, and particles of quartz sand are extremely rare or wholly absent (except in those regions affected in recent times by floating ice). The rate of deposition is very slow, and is at a minimum towards the central parts of the great ocean basins, where the depths are from 3000 to 5000 fathoms, and sharks' teeth, ear-bones of whales, manganese nodules, zeolitic minerals, and cosmic spherules are found in relatively great abundance. Deposits similar to those now forming in this abysmal area have not yet been traced in the geological series of rocks exhibited for examination on the continental areas. We may say that on one-half of the earth's surface there are now being laid down formations which are not similar to any found in the geological series.

TABLE I

Principal Lakes of the World arranged according to Superficial Area

Name of Lake.	Area in Square Miles.	Name of Lake.	Area in Square Miles.
Caspian *	180,000	Eyre *	3,200
Superior	31,200	Athabasca	3,000
Victoria Nyanza	26,200	Reindeer	2,490
Aral *	24,400	Issik-kul *	2,300
Huron (with Georgian Bay)	23,800	Vener	2,149
Michigan	22,450	Winnipegosis	2,080
Chad	20,000 to 7,700	Great Salt Lake *	2,000 to 1,750
Nyasa	14,200	Van *	2,000
Tanganyika	12,700	Albert	2,000
Baikal	11,580	Tung-ting	1,930
Great Bear	11,200	Manitoba	1,850
Great Slave	10,000	Urmi *	1,750
Erie	9,960	Poyang	1,640
Winnipeg	9,400	Bangweolo	1,500
Ontario	7,240	Lake of the Woods	1,500
Ladoga	7,000	Nepigon	1,450
Balkash	7,000	Peipus	1,350
Nicaragua	4,400	Kosso-gol	1,300
Onega	3,800	Chapala	1,300
Rudolf	3,500	Tsana	1,200
Titicaca	3,200	Kivu	1,100

* Lakes marked * are salt.

TABLE I—*continued*

Name of Lake	Area in Square Miles.	Name of Lake	Area in Square Miles.
Edward	1,000	Walker	95
Telezkoie	880	Hornafvan	93
Pyramid	828	Birket Qarun *	87
Toba	800	Neuchatel	85
Wollaston	800	Maggiore	82
Menzala	745	Zaisan	80
Vetter	733	St Louis	75
Saima	680	Corrib	68
Enare	550	Manapouri	56
Managua	500	Como	56
Lesser Slave	480	Rakas Tal	55
Mälar	450	Derg	49
St John	366	Lucerne	44
St Clair	360	Erne (Lower)	43
Dead Sea *	360	Thingvallavatn	40
Ilmen	358	Thonsvatn	38
Simcoe	300	Mask	35
Borollos	266	Zürich	34
Taupo	238	Rotorua	32
Balaton	230	Lomond	27
Geneva	225	Iseo	24
Constance	208	Crater (Oregon)	21
St Peter	200	Ness	21
Tahoe	193	Lugano	19
Hjelmar	185	Thun	18
Neagh	153	Bienne	17
Yellowstone	150	Waikaremoana	15
Garda	143	Erne (Upper)	15
Mjösen	139	Zug	15
Scutari	137	Mendota	15
St Francis	132	Awe	14
Utah	127	Rotoiti	14
Mariut	112	Brienz	11
Wakatipu	112	Maree	11
Manasarowar	110	Morat	11
Ochrida	105	Waikare	11
Edku	104	Walen	10
Magadi	100	Morar	10
Kolar	100	Tay	10

* Lakes marked * are salt.

TABLE II

Principal Lakes of the World arranged according to Volume

[The bracketed figures indicate in feet the mean depths, assumed for the purpose of calculating the volumes, in those cases where a mean depth was not otherwise available.]

Name of Lake.	Volume in Million Cubic Feet.	Name of Lake.	Volume in Million Cubic Feet.
Caspian (1000)	5,200,000,000	Neuchatel	500,000
Superior	413,000,000	Lucerne	417,000
Nyasa (1000)	396,000,000	Walker (150)	397,000
Tanganyika (800	283,000,000	Great Salt Lake (8)	390,000
Baikal	274,000,000	Mälar	353,000
Michigan	203,000,000	Iseo	268,000
Huron	166,000,000	Ness	263,000
Great Bear	84,000,000	Lugano	232,000
Ontario	61,000,000	Thun	230,000
Aral	43,600,000	Hjelmar (40)	206,000
Ladoga	43,200,000	Brienz	182,000
Issik-kul (600)	38,500,000	Thingvallavatn (150)	167,000
Titicaca	30,900,000	Waikaremoana	166,000
Nepigon	21,800,000	Neagh	161,000
Onega	21,000,000	Enare (10)	153,000
Erie	19,500,000	St Clair	150,000
Kosso-gol	18,200,000	Zürich	138,000
Winnipeg (50)	13,100,000	St Francis	132,000
Telezkoie (500)	12,300,000	Yellowstone	125,000
Vener	6,357,000	Zug	113,000
Victoria Nyanza (80)	5,800,000	Ilmen (10)	99,000
Dead Sea (500)	5,020,000	Lomond	93,000
Balkash (25)	4,880,000	Walen	88,000
Pyramid (200)	4,620,000	Morar	81,000
Tahoe (800)	4,300,000	Balaton	70,000
Geneva	3,175,000	Erne (Lower)	62,000
Mjösen	2,882,000	Scutari	60,000
Vetter	2,543,000	Corrib	59,000
Taupo	2,435,000	Tay	56,000
Van (40)	2,230,000	Mask	55,000
Wakatipu	2,205,000	Derg	47,000
Garda	1,766,000	Orta	46,000
Constance	1,711,000	St Peter	45,000
Ochrida	1,391,000	Bienne	44,000
Maggiore	1,310,000	Awe	43,000
Saima (60)	1,140,000	Maree	39,000
Rudolf (10)	976,000	Ericht	38,000
Peipus (25)	944,000	Lochy	38,000
Chapala (25)	906,000	Rannoch	34,000
Winnipegosis	869,000	Shiel	28,000
Como	794,000	Katrine	27,000
Hornafvan	777,000	Arkaig	27,000
Urmi (15)	732,000	Birket Qarun (10)	24,000
Manitoba	619,000	Sempach	22,000
Manapouri	512,000	Morat	21,000

TABLE III

Principal Lakes of the World arranged according to Maximum Depth

Name of Lake.	Max. Depth. Feet.	Name of Lake.	Max. Depth. Feet.
Baikal	5413	Treig	436
Caspian	3200	Rotomahana	427
Nyasa	2580	Shiel	420
Tanganyika	2100	Vetter	413
Crater (Oregon)	2000	Mistassini	400
Tahoe	1645	Wairaumoana	375
Mjösen	1483	Maree	367
Manapouri	1458	Glass	365
Issik-kul	1400	Thingvallavatn	364
Hornafvan	1391	Pyramid	361
Como	1345	Arkaig	359
Dead Sea	1278	More (Laxford)	316
Wakatipu	1242	Awe	307
Maggiore	1220	Valencia	300
Garda	1124	Vener	292
Chelan	>1100	Earn	287
Morar	1017	Sempach	285
Telezkoie	1017	Fannich	282
Geneva	1015	Assynt	282
Superior	1008	Quoich	281
Lugano	945	Morie	270
Ochrida	942	Great Bear	270
Titicaca	924	Monar	260
Michigan	870	Wastwater	258
Brienz	856	Muick	256
Waikaremoana	846	Bienne	249
Constance	827	Fada (Ewe)	248
Iseo	823	Victoria Nyanza	240
Ness	754	Green	237
Onega	740	Rotoiti	230
Ontario	738	Erne (Lower)	226
Ladoga	732	Llyn Cawlyd	222
Huron	730	Aral	222
Hornafvan	725	Affric	221
Thun	712	Suainaval	219
Lucerne	702	Windermere	219
Kosso-gol	676	Laoghal	217
Zug	649	na Sheallag	217
Lomond	623	Skinaskink	216
Kivu	>600	Garry (Ness)	213
Champlain	600	Erie	210
Nepigon	540	Mälar	210
Taupo	534	Damh (Torridon)	206
Lochy	531	Dùn na Seilcheig	205
Ericht	512	Frisa	205
Tay	508	Ullswater	205
Neuchatel	505	Mullardoch	197
Maracaibo	500	Mask	191
Katrine	495	Llyn Llydaw	190
Walen	495	Llyn Dulyn	189
Orta	469	Avich	188
Zürich	469	Hope	187
Rannoch	440	Saima	187

Table III—*continued*

Name of Lake.	Max. Depth. Feet.	Name of Lake.	Max. Depth. Feet.
Coniston	184	Bà (Mull)	144
Bad a' Ghaill	180	Scutari	144
Dhùghaill (Carron)	179	Llyn Glaslyn	127
Beannachan	176	Llyn Cwellyn	122
Laggan	174	Rotorua	120
a' Chroisg	168	Derg	119
Beinn a' Mheadhoin	167	Llyn Peris	114
Luichart	164	Joux	112
Dhulough	164	Medve	112
Shin	162	Ree	106
Beoraid	159	Oring-Nor	105
an Dithreibh	157	Haweswater	103
Morat	157	Neagh	102
Lurgain	156	"Lake on the Mountain"	100
Oich	154	Chapala	98
Dubh (Ailort)	153	Buttermere	94
St Mary's	153	Llyn Padarn	94
Owskeich	153	Winnipeg	90
Corrib	152	Managua	90
Coir' an Fhearna	151	Peipus	90
Obisary	151	Erne (Upper)	89
Nicaragua	150	Varese	85
Ennerdale	148	Mendota	84
Nafooey	148	Rotorua	84
Tiberias	148	Van	80
Lubnaig	146	Derwentwater	72
Scamadale	145	Bassenthwaite	70
Crummock	144	Hjelmar	65
Fionn (Gruinard)	144	Urmi	50

TABLE IV

Principal Lakes of the World arranged according to Altitude

Name of Lake.	Feet above Sea-level.	Name of Lake.	Feet above Sea-level.
Lapchung-tso	17,039	Jaring-Nor	13,900
Lighten	16,709	Titicaca	12,500
Yeshil-kul	16,207	Poopo	12,113
Ngangtse-tso	15,417	Koko-Nor	10,500
Teri-nam-tso	15,367	Twin Lakes	9,200
Tengri-Nor	15,190	Yellowstone	7,788
Zilling-tso	15,128	Naivasha	6,493
Manasarowar	15,098	Crater (Oregon)	6,239
Rakas Tal	15,056	Tahoe	6,233
Pangong	14,000	Tsana	5,800
Oring-Nor	13,900	Nakuro	5,668

TABLE IV—*continued*

Name of Lake.	Feet above Sea-level.	Name of Lake.	Feet above Sea-level.
Kosso-gol	5,470	Zaisan	1,350
Van	5,200	Zürich	1,341
Issik-kul	5,165	Sugota	1,300
Pyramid	4,890	Constance	1,300
Kivu	4,829	Wollaston	1,300
Urmi	4,400	Rudolf	1,250
Great Salt Lake	4,200	Taupo	1,211
Humboldt	4,200	Geneva	1,200
Walker	4,147	Llyn Cawlyd	1,165
Gyoljuk	4,000	Reindeer	1,150
Winnemucca	3,875	Lake of the Woods	1,060
Great (Tasmania)	3,800	Wakatipu	1,016
Victoria Nyanza	3,720	Orta	951
Bangweolo	3,700	Chelan	950
Kereli	3,600	Rotorua	915
Kania	3,500	Rotoiti	910
Choga	3,396	Lugano	889
Baringo	3,325	Chad	850
Joux and Brenet	3,307	Dauphin	840
Mweru	3,189	Ala-kul	837
Losuguta	3,050	Winnipegosis	828
Edward	3,004	Manitoba	810
Ngami	3,000	Balkash	780
Toba	3,000	Varese	778
Buldur	2,900	Laach	750
Egerdir	2,800	Simcoe	701
Tanganyika	2,624	Winnipeg	700
Rukwa	2,560	Haweswater	694
Tuzlah	2,525	Athabasca	690
Ochrida	2,253	Nepigon	665
Lob-Nor	2,200	Como	653
George (Australia)	2,100	Nepissing	644
Magadi	2,050	Maggiore	636
Albert	2,028	Superior	627
Nahuelhuapi	2,000	Temiscaming	612
Natron	1,996	Iseo	610
Llyn Glaslyn	1,971	Michigan	581
Shirwa	1,946	Huron	581
Summit	1,940	Erie	573
Stefanie	1,900	St Clair	570
Kaniapiskau	1,850	Ullswater	476
Thun	1,837	Llyn Cwellyn	464
Brienz	1,824	Derg (Donegal)	457
Llyn Dulyn	1,747	"Lake on the Mountain"	427
Telezkoie	1,700	Enare	394
Sempach	1,663	Great Slave	391
Nyasa	1,645	Fertö	370
Baikal	1,588	Ennerdale	368
Lucerne	1,433	Balaton	344
Morat	1,427	Great Bear	340
Bienne	1,417	Llyn Padarn	340
Neuchatel	1,417	Llyn Peris	340
Llyn Llydaw	1,416	Buttermere	329
Hornafvan	1,394	George (U.S.A.)	325
Walen	1,378	Crummock	321
Zug	1,368	Vetter	289
Mistassini	1,350	St John	278

TABLE IV—*continued*

Name of Lake.	Feet above Sea-level.	Name of Lake.	Feet above Sea-level.
Saima	256	Dhulough	108
Ontario	247	Ilmen	107
Derwentwater	244		
Onega	236		Feet below Sea-level.
Bassenthwaite	223		
Garda	213		
Wastwater	200		
Aral	160		
Vener	144		
Coniston	143	Eyre	39
Windermere	130	Caspian	86
Glencullin	128	Birket Qarun	140
Ree	122	Assal	222
Nicaragua	110	Tiberias	682
Derg	108	Dead Sea	1292

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["Bibliography is never finished, and always more or less defective, even on ground long gone over. The writer would be accurate; yet he feels the weight of Stevens' satire: 'If you are troubled with a pride of accuracy, and would have it completely taken out of you, print a catalogue.'"—ELLIOTT COUES.]

INDEX OF GENERA AND SPECIES

GENERAL INDEX

[Bibliographies excluded.]

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