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THE PHYSICAL GEOLOGY AND GEOGRAPHY OF GREAT BRITAIN;

A COURSE OF SIX LECTURES

DELIVERED TO WORKING MEN

IN THE MUSEUM OF PRACTICAL GEOLOGY,

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IN JANUARY AND FEBRUARY, 1863,

BY

PROFESSOR A. C. RAMSAY, F.R.S.

PRESIDENT OF THE GEOLOGICAL SOCIETY.

No. IV.

DISTRIBUTION OF THE MIOCENE AND PLIOCENE TERTIARY STRATA, GLACIAL PHENOMENA, AND ORIGIN OF CERTAIN LAKES.

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PROFESSOR RAMSAY'S LECTURES.

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A. C. Ramsay.

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Special effects of the Physical Geology of the Country on Population and Industry.

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LECTURE IV.

DISTRIBUTION OF THE MIOCENE AND PLIOCENE TERTIARY STRATA. GLACIAL PHENOMENA; AND ORIGIN OF CERTAIN LAKES.

We now come to the Middle and Upper Tertiary strata, the first of which consists of the Miocene beds. Their position is shown on the geological scale at page 19, above the upper Eocene beds. They, however, play such a very unimportant part in the *physical geology* of the mass of the country, that I shall dismiss them in a very few words.

The Miocene beds, are only known in Britain in the island of Mull, one of the Western islands of Scotland, where there are certain strata of shale, interstratified with beds of basalt and volcanic ash, first described by the Duke of Argyll, and known to be of Miocene date, because of the plants which occur in them, all being distinct from any living species, and many the same as those well-known to be of Miocene age, in Bohemia, on the banks of the Rhine, in Switzerland, and in other places where Miocene formations are well developed.

In the south-west of England, in the neighbourhood

of Dartmoor, at a place called Bovey Tracey, in a flat area ten miles long by two miles wide, there are also found beds of Miocene clay interstratified with bands of imperfect lignite; and of late these beds, the age of which was for long a puzzle, have been investigated through the liberality of Miss Burdett Coutts, who paid all the expenses to enable a gentleman in that neighbourhood to investigate the nature of these strata, because there were no commercial works there of sufficient importance to develop them; and it required digging in order to enable one to arrive at just conclusions as to the nature of the strata. The result was, from an examination of the fossil plants in these beds, that they were also found to be all of Miocene age, that is to say of middle Tertiary date; and it is an important fact which I may mention, that these plants are not only found here and there in Scotland, Ireland, and England, in Bohemia, and on the Rhine, but many of them also occur in Iceland, and in North America and Greenland, beyond the Arctic circle. The meaning of this is not yet understood, for many of the plants are of a nature that seem to bespeak a warmer climate than that of the British Islands at the present day, and it is difficult to see how such plants could grow in Arctic regions, where there is not the stimulus of light during half the year. This is one of those things which we cannot explain, and about which we are waiting for light.

Above the Miocene beds come the Pliocene strata; that is to say beds still newer in the series, and these

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in the lower part consist of sub-divisions generally known as the Crag (a workman's term). At the base lies the Coralline Crag, so-called because it contains a large number of corals.

Above this lies the Red Crag, which in some places is not conformable to the Coralline Crag below, showing that an interval elapsed between the deposition of the strata. Newer than the Red crag is the Norwich or Mammaliferous crag, differing in many details from either of the others. All of these occupy certain minor patches in Norfolk and Suffolk; and here and there on the borders of the Weald, in some situations on the very top of the Chalk Downs, there are small patches of sand which are provisionally placed by some geologists on the horizon of part of the Crag. But this is doubtful. The lower, or Coralline crag, contains 51 per cent. of existing species of shells. The Red crag has a still larger proportion of existing species, showing that it approaches nearer to our own day, not only because it lies above the Coralline Crag, but also because there is a still greater per centage of living species, mixed with the fossil remains; and along with the shells which form the chief mass of that formation, there are found the bones of a few species of Mammalia, some belonging to the sea, and others to the land. Those of marine origin are cetacean, as the whale; and along with these, also occur the remains of the Mastodon, a remarkable kind of Elephant, with teeth which differ very much from that of the true elephant in certain particulars, which, however, it is not

my object now to explain. Then, in the Mammaliferous crag of newer date, we have a larger proportion of Mammalian remains, hence its name. In it have been found the bones of the same species of Mastodon, also of an extinct elephant, of the ass, the beaver, and a great number of other smaller animals. I mention these things, not because these formations play an important part in British physical geography, as they are generally so far buried under superficial gravels of one kind or another that they require to be looked for, and thus do not at all affect the scenery, but to show you the kind of changes that our country, in comparatively late times, must have undergone. It has undergone these changes in late times, but far greater are the numbers and the kind of changes that it must have undergone in periods that went before.

We are not of necessity to consider Great Britain as having always been an island during and between the periods that I have already described. It is an accident that it is now an island; and it has been an island or islands probably many times before, in many shapes; and when you consider that we have here two epochs of the Crag, both containing remains of great terrestrial animals, you will see that it must have been joined at times to the main land, for otherwise these great terrestrial animals could not have found their way into our area. As I describe other periods, still later than the Crag, we shall be able to show definitely a little more the precise kind of changes that our land in latter days has undergone.

Younger than the Crag there are certain other minor deposits, portions of which are scattered here and there throughout England. They are definite enough to those who study fossil remains, but as they scarcely affect the features of the country, I shall say nothing about the causes that brought about a little patch here and a little patch there of gravel or loam, in which we may find relics of the hippopotamus, the rhinoceros, and other mammalia.

But I now come to a remarkable episode in Tertiary times, known as the *Glacial epoch*, of later date than some of those mentioned above, and of earlier date than others, which has left its traces universally over the whole northern half of the northern hemisphere, and also over a large portion of the southern hemisphere; and I hope I shall be able to describe the history of that period as it affects the scenery of Britain with something like tolerably accurate detail. Before doing so, however, I must lead you into Switzerland, and show you what kind of effect is being produced there by the ice of the present day, and afterwards into Greenland, and show you what takes place there, and then by the knowledge thus gained, I shall be able to bring you back into our own country, and show what took place here in that glacial period which is so far distant, but which, by comparison with the more ancient periods, almost approaches our own day.

Now then, the first thing I have to do, is to describe what a glacier is. In this map so highly coloured you will see certain white patches here and there on the

higher mountain ranges of the Alps.* The highest mountain in the Alps, Mont Blanc, rises more than fifteen thousand feet above the level of the sea, and there are other mountains in this great chain which approach that height, ranging from 12,000 to 15,000 feet. The mean limit of perpetual snow upon the Alps, is 8,500 feet above the level of the sea. Above that line, generally speaking, the country is covered with snow, and in the higher regions it gathers in the large recesses, and lying upon the mountain slopes, by force of gravity it presses downwards into the main valleys; where, in consequence of the immense pressure exerted by the weight and movement of this accumulated mass, the snow year after year is converted into ice. Without entering on details, it is enough if I now state that experiment proves this, in addition to well-considered observations made by the best observers of the icy phenomena of the Alps. Still accumulating, year upon year, by degrees this ice slides down the valleys, and is often protruded in a great tongue far below the limits of perpetual snow, for some glaciers descend as low as from *three* to *four* thousand feet or thereabouts above the level of the sea, whereas the limit of perpetual snow is 8,500 feet. Now I will not enter into all the details of the structure of glaciers, because that will not help us in the special investigation we have now in view; but I will describe to you what are the effects produced by a glacier in the country

* Reference was here made to a large map of Switzerland, showing the modern glaciers and their ancient greater extension.

over which it slides, and various other glacier-phenomena affecting the scenery of the Alps, and therefore affecting the scenery of our own country in past times when glaciers existed here, and still affecting it in the relics they have left.

A glacier slides down a valley more or less rapidly, according to the mass of ice that fills the valley, and also according to the greater or less inclination of the slope, for in this respect it behaves exactly like a river. If you have a vast body of water like the Mississippi flowing down a broad valley, although the slope of the valley may be very gentle, still the river flows with great rapidity in consequence of the greatness of the body of water; so if you have a mass of ice, which represents the snow drainage of a large tract of country, covered *with perpetual* snow, then the *glacier flows with a rapidity proportionate to the mass of ice,* and that is modified, increased, or diminished, in accordance with the angle of the valley over which it flows, so that when the valley is steep, the glacier flows comparatively fast, and when the angle at which the valley slopes is small, it flows comparatively slow.

All glaciers are traversed by cracks which are termed *crevasses.* Now the mountain peaks that rise above the surface of a glacier in some cases are so steep that the snow refuses to lie upon them, even when they may happen to be above the limits of the average line of perpetual snow, so that masses of rock are always being weather-worn by atmospheric disintegration, and falling from the slopes they find a temporary resting place

on the surface of the ice at the margin of the glacier, and, as it were, float upon its surface in long and continuous lines; for the motion of a glacier is so slow, that the quantity of stones that fall upon its surface, is sufficiently numerous to keep up a continuous line of blocks of earth and gravel, often of great width. These stones, when two glaciers combine to form one great trunk, as in the glacier of the Aar, at a certain point meet and form one grand line running down the centre of the glacier. These are termed *moraines*, and at length great part of this material arrives at the end of the glacier, and falls into the valley at the end of the ice-stream, frequently forming large mounds, known as *terminal moraines*.

Beneath every glacier water is constantly flowing, caused by the melting of the ice both below and on the surface of the glacier. In the upper regions where crevasses are not numerous, you frequently find large brooks so wide that you cannot leap across them, and you may have to walk half a mile before you find a passage. The water therefore that runs from the end of a glacier very often emerges from an ice-cavern as a large ready made muddy river, which carries away the moraine rubbish that the glacier deposits at its lower end, in some cases almost as fast as it is formed; perhaps I might rather say as slowly as it is formed, because if you go day after day you might see scarcely any difference even in the detail of certain moraines, though in time the stones shed from the ice are carried away by the river down the valley. In other

cases, however, it happens that from various circumstances moraines are preserved from destruction, and form permanent features in the scenery.

Now I have something special to say about moraine-stones before I describe the glacial phenomena of our own island. When a glacier passes over solid rocks, an immense weight of ice, in some cases, as in Greenland, thousands of feet in thickness, by pressure of this slow moving mass, the rocks in the valley over which the glacier passes become smoothed and polished, not flatly but in wavy lines, presenting a largely mammilated surface. Furthermore, the stones of the surface moraines frequently fall into crevasses and the small debris and finely powdered rocks that more or less cover the surface of a glacier, are also borne into these crevasses by the water that flows upon the surface; the consequence is that the bottom of the glacier is not simply bare ice, but between the ice and the rock over which it flows, there are blocks of stone imprisoned, and silicious and feldspathic debris, which may be likened to emery powder. The result is that let the rock be ever so hard, it is, in time, polished almost as smooth as a sheet of glass, and this polished surface is scratched and grooved, by the debris that being imprisoned between the ice and the rocky floor is pressed along in the direction of the flow of the ice. By degrees, grooves and deep furrows are thus cut in the rock over which the ice passes.

But the stones that are imprisoned between the ice and the rocky floor not only groove the rocky floor itself,

but in turn become scratched by the harder asperities of the rocks over which they are forced; and thus it happens that many of the stones of moraines *are scratched* irregularly, so that we are often able by this means to tell, independently of the forms of the heaps, whether such and such a mass is a moraine or not.

These indications of the rounding, smoothing, scratching and grooving of the rocks in lines co-incident with the flow of the glacier, together with old moraine heaps and scratched stones, are so characteristic of all glaciers, that by this means we are able to detect the important fact that the Swiss glaciers were once of far larger dimensions than they are now, and that they have gradually retreated to their present limits. Far below the present ends of the Swiss glaciers, 50 or 80 miles further down the valleys, we find all the signs I have described and others besides frequently as marked as if the glacier had only left the rocks before the existing vegetation began to grow upon their surfaces.

Such being the case in Switzerland, where we have been able to study the action of glaciers in detail, we have next to enquire, is there anything further to learn in regions where glaciers are on a far greater scale? Those who have read the descriptions of navigators, will be aware that in Greenland, the glacier line, as a whole, descends lower and lower as you go northward, till in the extreme north the whole country is one universal glacier. The same universal covering of ice is found in that southern land, discovered by Ross,

and known as Victoria Land, where the mountains rise some of them ten, twelve, and fourteen thousand feet above the sea, and except here and there, where there are steep cliffs, they are covered with a coating of thick ice. In Greenland, where the Coast cliffs happen to be high and steep, the glaciers break off at the top of the cliffs and fall in shivered icebergs into the sea, but when valleys fairly open into the sea then it frequently happens that prodigious glaciers push their way across the land out to sea, and are in certain cases 10 or 20 miles across at the mouth. In the extreme north the ice has been described as proceeding out to sea, and forming a continuous cliff of ice far outside the true rocky coast, as far as the eye can reach. Some of these vast glaciers have been estimated as being at the very least 3000 feet in thickness, and great masses of ice breaking away from their ends, form icebergs, which frequently laden with moraine rubbish, just like that which covers the glaciers of Switzerland, float out into the Greenland sea, and are carried south, along the coast of North America, by a sea current. Some of these bergs are known to pass below the parallel of New York, and they even have been seen off the Azores. Melting by degrees as they come into a warmer climate the stony freight is scattered abroad, here and there over the bottom of the Atlantic, which thus becomes strewn with erratic blocks, and other debris borne from far northern regions.

Now, then, I have got to apply these remarks in our own island. Having ascertained what are the signs

by which a glacier may be known, I have to show that a large part of the British islands has been subjected to what we call *glaciation*, or the action of ice. Those who know the mountains of the Highlands of Scotland remember that though the weather has had a powerful influence upon them, rendering them in places rugged, jagged, and cliffy; yet, notwithstanding, their general outlines are often remarkably rounded and flowing; and when you examine the valleys in detail you also find that in their bottoms and on the sides of the hills, the same mammillated structure prevails. This rounded form is known to those who especially devote themselves to the study of glaciers by the name of *roches moutonnees*, a name now in general use in England, because it happened that in Switzerland glaciers were first described by authors who wrote in French. These mammilated forms are exceedingly common in many British valleys, and not only so but the very same kind of grooving and striation, so eminently characteristic of the rocks in the Swiss valleys, also marks those in the Highlands of Scotland, of Cumberland, and of Wales. Considering all these things, geologists, led twenty-three years ago by Agassiz, have by degrees almost universally come to the conclusion that a very large part of our island was, during the glacial period, covered, or nearly covered, with a coating of thick ice, in the same way that the north of Greenland is at present; so that from the long-continued grinding power of a great glacier or set of glaciers nearly universal over our country, the whole surface be-

came moulded by ice, and the relics of this action still remain strongly impressed on the country, to attest its former power. It might be unsafe to form this conclusion merely by an examination of such a small tract of country as the British islands, but when you examine the great Scandinavian chain, and the north of Europe generally, you find that similar phenomena are common over the whole of that area; and in the North American continent, as far south as latitude 38° or 40°, you, find when you remove the soil, or the superficial covering of what is called drift, and get at the solid rock beneath, almost every where it is smoothed and polished, and covered with grooves and striations similar to those of which we have experience among the glaciers of the Alps. We know of no power on earth, of a natural kind, which produces these indications except ice, and therefore geologists are justified in attributing them, even on this great continental scale, to its action.

You will presently see that this conclusion is fortified by several other circumstances which I shall proceed to mention. Thus, at a late Tertiary period in the Alps there is evidence that the glaciers were once on an immensely larger scale than at present. The proof as usual lies in the existence of polished and grooved rocks, and of numerous moraines on a scale so immense that the largest of the present day are mere pigmies when compared with them. The same kind of phenomena occur in the Himalayah, the Andes, and in almost every northern mountain chain or cluster, great or

small, that has been examined critically, and therefore there can be no doubt that at a late period of the world's history an extremely cold climate prevailed over much larger tracts of the earth's surface than at present, produced by some cause which geologists have not yet got to the bottom of.

It was at this period that a great part of what is now the British islands was covered with ice. I do not say that they were islands at that time, I think they were not; they were probably united with the continent, and the average level of the land may by elevation of the whole have been much higher than at present; but whether this was so or not, the mountains and much of the lowlands were covered with a universal coating of ice, probably as thick as that in the north of Greenland in the present day. While this large glaciation was going on a slow submersion of the land took place; and as it sank the glaciers, descending to the level of the sea, deposited their moraine rubbish there. Gradually the land sunk more and more, the cold still continuing, till this country, previously united to the continent of Europe, became a group of icy islands, still covered with snow and small glaciers, which descended to the sea and broke off in bergs, which floating south deposited their stony freight as they melted. The proof of this is to be found in the detritus which covers so much of Scotland, and the north of England, composed of clay and gravels, mixed with stones and great boulders, many of which are scratched, grooved, and striated, in the manner of which we may be said to

have every-day experience in the glaciers of Switzerland, Norway and Greenland.

Much of this clay is known as the Till in Scotland; and it was only by very slow degrees, that geologists became reconciled to the idea that this Till is nothing but moraine rubbish on a vast scale, formed by those old glaciers that once covered the northern part of our country. In fact, Agassiz who held these views, and Buckland who followed him, were something like twenty years before their time; and men sought to explain the phenomena of this universal glaciation by every method but the true one. Mr. Robert Chambers was I think the first after Agassiz, who asserted that Scotland had been nearly covered by glacier ice, and now the subject is being worked out in all its details; thus coming back to the old generalised hypothesis of Agassiz, which is now accepted or on the very verge of acceptance by most of the best geologists of Europe and America.

Besides the scattered boulders, we know that the country was descending beneath the sea during this glacial epoch for another reason,—that here and there, in the heart of the moraine-matter of the Till, there are patches of sand and clay inter-bedded. The mass indeed is not stratified, because glaciers do not stratify their moraines, but the waves playing upon them, as they were deposited in the sea, here and there stratified portions; and there occur, at rare intervals, in these patches in Scotland,* the remains of sea-shells of

* Lately described to me by Mr. Geikie, in the Scotch Till.

species, such as now occur in the far north. Here, therefore, we have another proof of that arctic climate which, in old times, came so far south.

In Wales we find similar evidence of the sea having risen at least 2,300 feet upon the sides of the mountains, for Wales also became a cluster of islands, round which the drift was deposited, and great blocks of stone were scattered abroad, floated on icebergs that broke from an old system of glaciers, and melted in the neighbouring seas. In this stratified material sea-shells were long ago found in Caernarvonshire by Mr. Trimmer and myself, from 1000 to 1300 feet above the sea.

Erratic blocks of granite, gneiss, of feldspathic traps, and of other rocks, some of which came from the highlands of Scotland, some from the Cumberland mountains, some from the Welsh mountains, and some from the further region of the great Scandivanian chain, were in the same manner spread over the central counties and the east and west of England, just like those boulder-beds that are now being formed at the bottom of the Atlantic from the icebergs that float south from the shores of Greenland.

But England, south of the estuaries of the Severn and the Thames, for the most part seems all this time to have remained above the waters, for not only is the country in general destitute of drift, but it is only close on the sea near Selsea and Brighton that erratic boulders have been found.

After a long period of submergence the country

gradually rose again, and the evidence of this I will prove, chiefly from what I know of North Wales, although I could easily do the same by taking you into the highlands of Scotland. But North Wales is possibly more familiar to some here present.

I shall take the Pass of Llanberis as an example. There is all the common proofs of the valley having been filled with glacier-ice. When the country was below the water, the drift was deposited, and more or less filled up many of the valleys of Wales. When the land had risen a second time to a considerable height, the glaciers again increased in size, although they never reached the immense magnitude which they attained at the earlier portion of the glacial epoch. Still, they became so large, that such a valley as the Pass of Llanberis was a second time occupied by ice, and the result was, that the glacier ploughed out the drift and loose rubbish, that more or less covered the valley. Other cases of the same kind could easily be given, while in many valleys you find the drift still remaining. By degrees, however, as we approach nearer our own days, for unknown reasons, the climate began to ameliorate, and the glaciers began to decline, till growing less and less, they crept up and up, and here and there as they died away, they left their terminal and lateral moraines, still as well defined in some cases as moraines in lands where glaciers now exist. Frequently too masses of stone, that floated on the surface of the ice, were left perched upon the rounded *Roches*

moutonnées, in a manner somewhat puzzling to those who are not glacial geologists. They often lie in such positions that they clearly cannot have rolled down from the mountain above, because their resting places are separated from it by a valley; and besides many of them lie in positions so precarious, that if they had rolled down from the mountains they must, on reaching the points where they lie, have taken a final bound, and fallen into the valley below. But when you are experienced in glacial geology, your eye detects the true cause of these phenomena, and you have no hesitation in coming to the conclusion, that as the glacier declined in size, they were let down upon the surface of the rocks so quietly and so softly, that there they will lie, until an earthquake shakes them down, or until the wasting of the rock on which they rest precipitates them to a lower level. Finally, the climate still ameliorating, the glaciers shrunk further and further into the heart of the mountains, until, at length, here and there in their very uppermost recesses, you find the remains of tiny moraines marking the last relics of the ice, before it disappeared from our country.

All these things give distinctive characters to our mountains, very different from those of mountain ranges where glaciers never were.

I purposed in this lecture to have described the river gravels which contain those prehistoric remains which of late have excited so much interest. But on considering the subject it seems to me more in rule first to attend

to certain other points that materially affected the geography of our country, and that is the glacial origin of many of our lakes.

When glaciers descend into valleys, and deposit their terminal moraines, it has sometimes happened that when a glacier declined in size its moraine still remained tolerably perfect, and the result is that the drainage formerly represented by ice is now represented by running water, which is dammed in between the surrounding slopes of the solid mountain and the mound formed by the terminal moraine, thus making a lake. There are such lakes on the Italian side of the Alps, and there are several among the mountains of Wales. Whether there are any in Cumberland I do not know, but as yet I have seen none in Scotland dammed by the terminal moraine of a common valley glacier, although I have no doubt that they may exist in parts that I have not visited. Furthermore, sometimes on the outside of these moraines we find the old stratified boulder-drift, showing that the old glacier descended to the level of the sea and deposited its moraine there, and breaking up, floated about as icebergs bearing boulders. By-and-bye, as in other cases, the glacier that was produced by the drainage of snow disappeared and is now represented by water, forming a lake dammed by a moraine, outside of which lie long smooth slopes of stratified drift.

Such lakes are always on a small scale, but there are others on a larger scale, having a far more important bearing upon the physical geography of our

country, and of many other countries belonging to the northern hemisphere. The theory which I am going to propound to you is my own, and is not very old. It gave rise to a very considerable amount of opposition, and also, to some approval, and I believe that in time it will be sure to make its way.

There is no point in physical geography more difficult to account for than the origin of most lakes. When thought about at all, it is easy to see that lakes are the result of the formation of hollows, a great proportion of which are true *rock-basins*, that is to say, in hollows entirely surrounded by solid rocks, the waters not being retained by loose detritus. But the great difficulty is how to make the hollows. If you, in the first place, will consider what is the effect of marine denudation; on the sea-shore, where the waves are always breaking, the effect of this and of the weathering of the cliff where it rises above the waves is to waste back the land. But the sea never makes a hollow below its own level; what it does, if there are any hollows there, is to fill them up with detritus; it cannot make them, or cut them out. The consequence is, that all the sea does is to act as a great planing machine, wearing off the larger irregularities that rise above its level. Now what takes place in the interior of the country by the influence of running water? Rivers cannot make hollows that are surrounded by rocks on all sides. All that running water can do upon the surface is to scoop out a trench or a channel of greater or less width. If you have an original surface

with a long slope, gentle or steep, as the case may be, water will run upon it because of the slope, and it will wear out a channel on an inclined plane, but it cannot make a basin.

Now, when you have come to this conclusion, you will see that it is difficult to account for the existence of hollows, composed of hard rocks, which completely inclose lakes. It may be contended that they were formed by the disturbance of the rocks, so as to throw them into a basin-shaped form. But when we take such lakes as that of Geneva, the Lake of Thun, and the Lakes of Lucerne, Zurich, Constance, and the great lakes on the Italian side of the Alps, and examine the rocks critically, you find that they are not in a basin-shaped form, but the strike of the strata often runs across the lakes. Neither, as I have shown in the Journal of the Geological Society, do the Swiss valleys generally, or the lake-valleys in particular, lie in great rents or fissures, an opinion also held by one of the first physical geologists in Europe, Escher Von der Linth. It might, however, be said that these lakes lie in areas of special depression made by the sinking of the land underneath each lake. They are, however, so numerous in the Alps, and in the highlands of Scotland where they occur by the hundred, and in North America by the thousand, that I feel sure the theory of a particular depression for each lake will not hold. In North America it is as if the whole country were sown broadcast with lakes, large and small, and not being very mountainous, but consisting in great part of undulating flats, it becomes

an absurdity to suppose that for all the lakes, so close together, a special area of depression was provided for each. The physical geology of America and of Scotland, entirely goes against such a supposition, and I believe, though the subject is more difficult, it is equally untenable for the Alps, and the lowlands between the Alps and the Jura.*

Now then, if we have disposed of these hypotheses for the formation of such hollows, what is left? If the sea cannot do it, nor weather nor running water, and if the hollows were not formed by synclinal curves of the strata, and if they do not necessarily lie in rents and fissures, the only remaining agent is the denuding power of ice. In the region of the Alps it is a remarkable circumstance that in the courses of the great old glaciers all the larger Alpine lakes lie—each one of them, in a true rock basin. This is important, for though it is clear that the drainage of the mountains must have found its way into these hollows, either in the form of water or of glacier-ice, yet if ice had nothing to do with their formation, we might expect an equal number of lakes great and small in other regions where the rocks are equally disturbed or of like nature, but where there are no traces of glaciers. I have never observed that this is the case but rather the reverse.

I will take the Lake of Geneva as a special example

* For details see Quarterly Journal of the Geological Society, 1862, p. 185. There are some lakes known to occupy areas of special depression, for I by no means wish you to understand me as asserting that this theory accounts for the probable origin of every lake in the world.

before applying the theory to our own country. This lake is about forty miles long, and in its widest part about twelve miles wide. It lies at the mouth of the valley of the Rhone and directly in the course of the great old glacier, which was something like a hundred miles in length from its source to where it abutted upon the range of the Jura mountains, by 125 miles from west to north-east at its end. It is known to have been so large by the effects produced on the country over which it flowed, and also by the fact that blocks of gneiss, granite, and others of Alpine origin are found scattered on the flanks of the Jura, associated with moraine matter in such a way as to leave the former existence of that old glacier beyond a doubt.

The Lake of Geneva in its deepest part, near its eastern end, is 984 feet in depth, and it gradually shallows to its outflow. By examining the sides of the mountains on either side of the valley of the Rhone, through which the glacier flowed, we are able to ascertain what was the thickness of the ice in the valley when the glacier attained its greatest size, viz. nearly 2800 feet above the surface of the lake, or nearly 3800 if we add the depth of the water. By similar observations on the *Jura*, it is rendered clear, that where the glacier abutted on that range, it still maintained a thickness of something like 2200 feet where thickest. Now, consider the effect of such a mass of ice flowing over the surface of Miocene rocks, which in this part of Switzerland are comparatively soft, and yet of unequal hardness! That mass working on slowly and

steadily, for a period of time of untold duration, must have exerted a prodigious grinding effect on the rocks below. Where the glacier-ice was thickest — there the grinding power was greatest, and the underlying rock was to a very considerable extent destroyed and worn away; but where at its western end near Geneva the ice was thinner by reason of the melting of the glacier, there the pressure and grinding power was less, and the destruction of the underlying rock proportionally diminished. The result was that a great hollow was scooped out, at least 984 feet deep in the deepest part, and shelving up towards the present margin of the lake. When you think of this, you may at first deem it impossible, but when you compare the depth with the length of the lake, and reduce all to a true scale, you will then see that the depth is comparatively insignificant when the length of the hollow is considered, and the height and weight of the ice above.*

Therefore I have been forced to the conclusion, from a critical examination of many of the lakes in and around the Alps, that their basins were scooped out by the great glaciers of the glacial period; some of which were as thick or thicker than that which descended the valley of the Rhone.

Very well, then, if you examine the maps of the northern hemisphere generally, beginning at the equator and coming north, you will find very few lakes in its

* These points were illustrated by diagrams, as were all the other questions raised in this lecture.

southern regions. As you proceed northwards into America, in latitudes 38° and 40°, the lakes begin to increase and soon become tolerably numerous. As you go north of New York, and up towards the St. Lawrence, they become so numerous that they appear to be scattered over the whole country in every direction, and beyond this to the north and west of Lake Superior and the St. Lawrence, the whole country is dotted as thickly as they can be put upon the maps, and a vast number of them are omitted for want of room.

The whole of that country has been *completely* covered by ice—as the researches of geologists show. Coming to this side of the Atlantic, and examining the Scandinavian chain on the east, where the slopes are less than on the western flank, all round the Gulf of Finland, and the Baltic, the whole country is covered with lakes. Go into North Wales, where glaciers were common in every large valley, there we have the Lakes of Llanberis, of Cwellyn, Ogwen, Llyn-y-Ddinas, Llyn-Gwynant, Llyn-llydaw, and all the minor tarns in the upper Corries. You find many celebrated lakes in Cumberland—also an eminently glaciated country—and others unknown to fame besides. Go from these comparatively southern parts of our island, and examine Scotland; in Sutherland, and the Lewes, and in other Western islands; in Inverness-shire, Perthshire, Dumbartonshire, and the Mull of Cantyre—the whole country is sown with lakes—a vast number of which I can testify lie in true rock-basins, though some may merely lie in hollows made by unequal accumulation of

the drift. And all that country, like Greenland now, was in the glacial period ground by long enduring glacier-ice, which ice I firmly believe was the scooping power that originated most of the lake scenery of our country. I go further, for I have shown that in rocky regions, the further north you go, the more do lakes increase in number, and I am convinced that this fact is not a mere accidental coincidence, but is one of the strongest proofs of the former existence of that wide-spread coating of glacier ice, that in old times moulded the face of so much of the northern hemisphere.

June 28. Read again. Think I have got nearly all that this ~~good~~ geologist has got — & something ~~more~~ for This does not touch my notion of the blocking out of an arctic current by the rise of land in Scandinavia — It is therefore to be assumed that no one has yet hardly that theory to account for a glacial period. H.C.

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