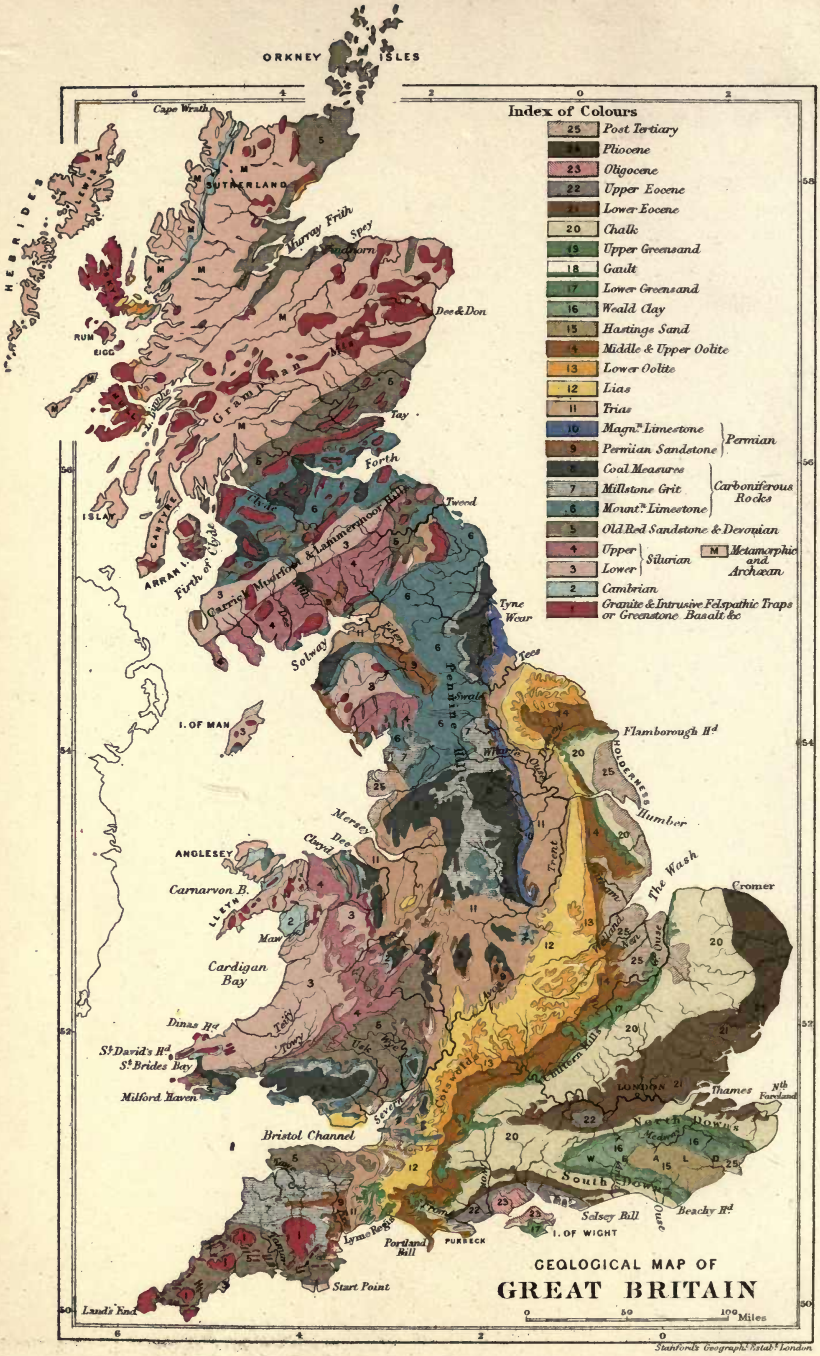

Stanford's Geograph. Estab. London

THE PHYSICAL GEOLOGY AND GEOGRAPHY OF GREAT BRITAIN:

A MANUAL OF BRITISH GEOLOGY.

BY THE LATE

SIR ANDREW C. RAMSAY, LL.D., F.R.S., &c.

Director-General of the Geological Survey of the United Kingdom.

WITH A GEOLOGICAL MAP, PRINTED IN COLOURS.

SIXTH EDITION,

EDITED BY

HORACE B. WOODWARD, F.G.S.

of the Geological Survey.

LONDON: EDWARD STANFORD,

26 & 27 COCKSPUR STREET, CHARING CROSS, S.W.

1894.

There rolls the deep where grew the tree,
O earth, what changes hast thou seen!
There where the long street roars, hath been
The stillness of the central sea.

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go.

TENNYSON.

EDITORIAL PREFACE.

This work originated in a course of six lectures delivered to working men, so long ago as 1863, in the Museum of Practical Geology. The object of that course, as stated by Sir Andrew Ramsay, 'was to show how simple the geological structure of Great Britain is in its larger features, and how easily that structure may be explained to, and understood by, persons who are not practised geologists.' In short, it was hoped that 'anyone with a very moderate exertion of thought may realise the geological meaning of the physical geography of our country, and, almost without effort, add a new pleasure to those possessed before as he travels to and fro.'

That the work was appreciated is shown by the fact that five editions were called for in a period of fifteen years. It is generally admitted that the second and third editions (1864 and 1872) most admirably fulfilled the original intentions of the author. The fourth issue (1874) was simply a reprint of the third. In these editions the freshness and vigour of the language, the manifest enthusiasm of the author and his sympathy, kindled a like enthusiasm in his readers.

In the fifth edition (1878) the work underwent a considerable transformation; by the addition of nearly three hundred pages it gained much valuable though detailed information, but thereby lost a good deal of the simplicity and charm of the earlier editions.

Sixteen years have now passed since that work left the hands of the author, and it is needless to say that during the interval great progress has been made in all departments of geology. It is well known that the views of the author, based on his long and wide experience, were often in advance of the general teachings in his day. New ideas flashed across his mind from time to time, and were afterwards incorporated in his book. It was these theoretical views that gave an especial stamp of originality to the work, and made it a source of inspiration alike to student and professor.

Filling a position different from that occupied by any other geological work, it has been felt that a new edition had become desirable, and by request of Lady Ramsay I have undertaken the preparation of this sixth edition. In this task I have had the advantage of the author's copy of the fifth edition, with many MS. corrections, and also of some MS. notes, kindly lent by Lady Ramsay. During the closing years of the author's life, he had, however, been prevented by failing health from keeping in touch with the progress of his favourite science. Born in 1814, he had nearly completed his seventy-eighth year when he passed to rest in December 1891, little more than three years ago. The story of his life has been told by Sir Archibald Geikie, to whose work the reader may refer for a full and interesting account of Sir Andrew's labours. Sir Archibald has kindly revised Chapter XXIX. of this book, dealing with the geology and scenery of Scotland; and I am indebted to Mr. Teall, Mr. Watts, and other colleagues for friendly advice and assistance. On myself a certain amount of responsibility rests for accounts of researches made during the past ten years. At best, it is no easy matter to edit a new edition of a scientific work that should be satisfactory both to the student and to the memory of the author; but the endeavour has been made to bring the information up to date, in accordance with the general tenor of the author's plan and teaching.

With regard to the illustrations, the selection of the groups of fossils was originally made for the author by Mr. Etheridge, while 'Mr. Sharman executed the drawings of these fossils with his accustomed skill and accuracy.' One additional figure has been added, that of *Olenellus*, from the restoration published by Professor Lapworth in the 'Geological Magazine' for 1891.

The diagrammatic sections are mostly from original drawings by the author; a few are now added from Professor James Geikie's 'Outlines of Geology,' 1886; these are acknowledged by the letters 'J. G.'

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The landscapes, as Sir Andrew has stated, were many of them engraved directly from his drawings in sepia and pencil. Fig. 83 was reduced from a coloured crayon drawing by Mr. Gillespie Prout; the original of Fig. 82 was drawn by Sir Henry De la Beche, and that of Fig. 85 by Edward Forbes. Figs. 81 and 128 were prepared from photographs.

The little map which forms the frontispiece has been revised so far as its small scale will permit. To the student the large geological map of England and Wales by Sir Andrew Ramsay, and that of Scotland by Sir Archibald Geikie, will be indispensable.

HORACE B. WOODWARD.

HIGHBURY:
May 14, 1894.

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CHAPTER I.

THE FORMATION AND GENERAL CLASSIFICATION OF ROCKS, AQUEOUS AND IGNEOUS.

In old days, those who thought upon the subject at all were content to accept the world as it is, believing that from the beginning to the present day it had always been much as we now find it, and that, till the end of all things shall arrive, it will, with but slight modifications, remain the same.

By-and-by, when Geology began to arrive at the dignity of a science, it was found that the world had passed through many changes; that the time was when the present continents and islands had no existence, for the strata and volcanic products of which both are formed, were themselves either sediments derived from the waste of yet older lands now partly lost to our knowledge, or newer accretions of volcanic matter erupted from below. Thus it happens that what is now land has often been sea, and where the sea now rolls has often been land; and that there was a time before existing continents and islands had their places on the earth, before our present rivers began to flow, and before all the lakes of the world, as we now know them, had begun to be.

Geology may therefore be defined as the science which investigates the history of the Earth, or the successive changes which have taken place in the land and water and their inhabitants. It discusses the causes of these changes, as far as they can be traced by observations on the structure and mode of occurrence of the mineral masses and of the animal and vegetable remains that form or are found in the *crust* of the Earth.

To arrange the events of this complicated history in clear chronological succession is the chief business of the geologist; and in so doing he unites the present with past geological epochs, and discovers that the physical world, as it now exists, is the result of all the past changes that have taken place in it. If, therefore, our knowledge were sufficient to admit of the construction of a complete system of modern physical geography, it would be a description of a geological epoch—namely, that of to-day; and a complete account of any old geological epoch would be a description of the physical geography of the world at that time.

To us, the chief dwellers on the Earth, the whole subject is of the greatest interest, and therefore we will endeavour to learn—taking our own island as an example—whence the materials that form the present surface of the Earth have been derived; why one part of a country consists of rugged mountains, and another part of high tablelands or of low plains; why the rivers run in their present channels; how the lakes came to diversify the surface.

Assuming that some readers may not have previously studied geological subjects in detail, it is needful first to discuss certain rudimentary points, so as to make the remainder intelligible to all. Therefore we begin with an account of the nature of rocks; because it is impossible to understand the causes that produced the various kinds of scenery of our country, and to account for the origin of its mountains and plains, without first defining the nature of the rocks which compose them.

All rocks, in the broadest sense, are divided into two great classes—Aqueous and Igneous; but there is an intermediate class, Metamorphic, formed by the alteration of aqueous or igneous rocks. The three varieties make up the solid surface of the globe, known as the Earth's crust. In this chapter we shall, however, consider the two great classes of rocks; those of *Aqueous* or watery origin, and those of *Igneous* origin, the products of subterranean heat.

By far the larger proportion of the surface-rocks of the world have been formed by the agency of water. Such rocks are made of *sediments*, and these sediments have been, and still are, chiefly the result of the action of atmospheric agencies, aided by chemical solutions, and of moving water.

Rain-water acts both chemically and mechanically on the crust of the earth. Many minerals in rocks, such as felspars, hornblendic minerals, mica, &c., are composed of silicates of alumina, with silicates of soda, potash, lime, magnesia, or iron. These are often associated with free silica. This is especially the case with some igneous rocks; and many of the stratified rocks consist in great part of substances of the same nature variously intermixed. Other aqueous rocks consist of carbonate and sulphate of lime, &c., more or less pure. Of these, the rocks made up of carbonate of lime, or the common limestones, by far predominate; they are sometimes nearly pure, forming immense areas of country, and are sometimes mechanically intermingled with other substances. All rain in falling absorbs part of the carbonic acid in the air; and the water percolating through the rocks unites with, and carries away in solution, portions of the soda, potash, lime, or magnesia that enter into the composition of the minerals in rocks, and this promotes their disintegration. They crumble, and are in a condition to be borne to lower levels, and finally to the sea, partly by the mechanical agency of running water, partly in solution.

Frost is also a powerful disintegrator. Water penetrates into hollows, joints, and cracks; it freezes and expands, and thus helps to rend and break up the rocky and earthy masses. Some of its most powerful effects are seen in the regions of glaciers and drift-ice; and to these phenomena attention will subsequently be drawn.

In cold climates, where special glaciers descend to the sea, bergs break off frequently laden with blocks and fine sediment, and floating seaward they deposit their freights where they chance to melt. By the breaking up of the ice-foot on sea-coasts, and of river-ice, large quantities of matter are also transported and scattered abroad. In dry and hot regions the extremes of heat and cold exercise as potent an effect in disintegrating rocks as does frost in higher latitudes. The sun's heat expands the rocks, and the cold at night contracts them, and thus fragments are detached. In the Desert of Sinai the sound of the cracking rocks can be distinctly heard through the night.

The quantity of material *degraded* and spread over the sea-bed by means of ice-agents is immense; it consists of mud, sand, gravel, and rounded, subangular, and angular blocks, often polished, grooved, and scratched; and from the irregular mode of its accumulation, and the frequent grounding and scraping of icebergs along the sea-bottom, the whole of this matter, if exposed, would present one of the rudest forms of stratification.

The chief agent, however, in the transportation of sediments from higher to lower levels is running water. Great thunderstorms, and sudden thaws in snow-covered lands, frequently produce startling effects, stripping large areas bare of soil, and hurrying to lower levels vast masses of earth, gravel, and boulders.

Everyone who has looked at large rivers knows that they are rarely pure and clear. The cause of this is obvious. All rain, especially if long continued, exercises a powerful mechanical effect on the surface of the earth, carrying much sediment into water-courses, which unite to form brooks, rivulets, and finally, if the country be large, great rivers. Soft surface-soil is thus easily carried away even in low countries, while in hilly and mountainous regions, sand, coarse gravel, and boulders, won from the adjoining rocks, are hurried onward; and thus great valleys and ravines have been formed in all parts of the world by running water, and by the long-continued attrition of stones driven onward by torrents over rocky surfaces. As the accumulated waters of rivers reach low lands, their power of transporting coarse sediment decreases, and finally, in great rivers, like the Rhine, the Nile, the Amazons, the Mississippi, and the mighty rivers of China, India, and Northern Asia, all but the finest sediment is deposited long before they reach the sea.

On a smaller scale in our country the same phenomena are obvious in such rivers as the Thames, the Severn, the Yorkshire Ouse, the Clyde, and the Tay. Every river, in fact, carries sediment and impurities of various kinds in suspension or in solution, and this matter, having been derived from the waste of the lands through which rivers flow, is carried to lower levels. Thus when rivers empty themselves into lakes—or, what is far more frequently the case, into the sea—the sediments which they hold in suspension are deposited at the bottom, and, constantly increasing, they gradually form accumulations which are arranged in *beds*, or, as geologists usually term them, in *strata*. Suppose a river flowing into the sea. It carries sediment in suspension, and a layer will fall over a part of the sea-bottom, the coarser and heavier particles near the shore, while the finer and lighter matter will often be carried out by currents and deposited further off. Then another layer of sediment may be deposited on the top, and another, and another, until, in the course of time, a vast accumulation of strata may be produced.

In this manner deltas are formed, and wide bays and arms of the sea have been silted up. As they fill, the marshes spread further and further, and, by overflows of the river bearing sediment, the alluvial flats rise higher and higher, till, as in cases like those of the Ganges and the Nile, kingdoms have been founded on mere loose detritus. A little reflection, too, will show that all lakes, be they ever so large, must, with sufficient time, get filled by this process with débris and become plains. Some of the old rocks of Britain are formed of sediments originally deposited in estuaries by rivers which may have been as large as the Mississippi or the Ganges; others were formed in lakes fresh or salt, bearing witness to ancient physical geographies; and many a modern flat surface in Britain, now covered by peat and traversed by a brook or a river, is only a lake-hollow filled with river-borne gravel, sand, and mud, overgrown by a marshy or peaty vegetation.

Again, if we examine sea-cliffs that rise direct from the shore, we find that the disintegrating effect of the weather brings down masses of rock, here and there, along the faces of the cliffs, thus supplying material for the formation of shingle. Then in gales the strong breakers driving the stones against the cliff form a 'powerful artillery with which the ocean assails the bulwarks of the land,' and aids in the work of destruction. On the east and south of England, where the strata consist largely of sands and gravels, clays and limestones, the waste of the softer strata has been very great; more especially in Suffolk, Norfolk, and Holderness in Yorkshire, where the loss, in places, has been between two and three yards a year. Where the strata are harder, as on the west coast, in Devon, Cornwall, and Wales, the waste is comparatively slow. Hard rocks, resisting waste because of their hardness, are apt to form headlands, while softer or more friable strata, wasting more rapidly, often occupy the recesses of coves and bays. (See Fig. 1.) The removal of the fallen detritus by the restless waters makes room for further slips of débris from above, and thus it happens that all sea-cliffs are in a state of constant recession, comparatively quick when made of clay or other soft strata; perhaps very slow, but still sensible to the observant eye, when the rocks are harder, so that in time, be they ever so tough, they get worn more and more backwards. The material derived from this waste when sea-cliffs are truly rocky, generally forms, in the first instance, shingle at their bases, as, for example, with the pebbles of flint formed by waste of the Chalk which contains flints. These, being attacked by the waves, are rolled incessantly backwards and forwards, as everyone who has walked much by the sea must have noticed; for, when a large wave breaks upon the shore, it carries the shingle forward, rolling the fragments one over the other, and in the same way they recede with the retreating wave with a rattling sound. As in the running water of torrents, so this long-continued marine action has the effect of grinding angular fragments into more or less rounded pebbles;

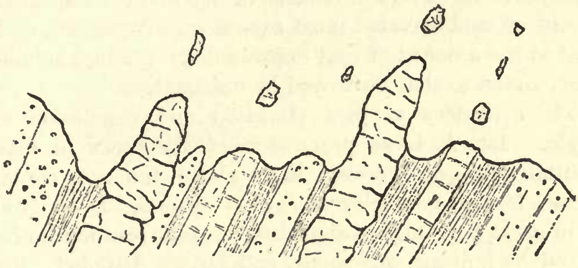


Fig. 1.—Ground-plan of Sea-coast. (J. G.)
Irregular outline due to alternation of durable and less durable rocks.

and, in the course of time, large quantities of loose gravel or shingle have thus been formed. Such material when consolidated becomes a *conglomerate* or *pudding-stone.*

If, also, we examine with a lens the sand of the sea-shore, we shall find that it is formed of innumerable grains of quartz; these grains are generally not quite angular, but are more or less rounded, their edges having been partly worn off by the action of waves and tides moving them backwards and forwards upon each other. When the sand is blown about by the wind the grains are much more rounded. Such material forms *sandstone* when consolidated by the infiltration of cementing material, such as iron in various forms, carbonate of lime, silica, &c.

Finer-grained and muddy deposits, in like manner, are generally formed of the minutest grains of sand, mixed with clayey or aluminous substances originally derived from the waste, perhaps, of felspathic rocks. Such material, when soft, forms *clay*; when consolidated, *shale*; and when it has undergone much lateral pressure, *slate*. (See Fig. 137.)

With sufficient time all land, by these processes of waste, would be eventually degraded beneath the sea (as was suggested by the old naturalist Ray), were it not that the loss is compensated by disturbance and elevation slowly taking place over certain portions of the Earth's surface. Large areas are also slowly depressed beneath the sea; but to maintain the average balance of sea and continent, the amount of land elevated must exceed that depressed, or be equal to the amount of that depressed by gradual submergence, added to that destroyed by degradation.

The evidences of past elevation and depression are simple. 1st. A large proportion of the rocks in many mountain ranges, however high above the sea, contain marine fossils, generally of extinct species. Such strata are in great part highly disturbed, broken, contorted, often pierced by igneous intrusions, and largely denuded. 2nd. On many continents and islands raised beaches are found, lying on the older rocks, and yielding shells, in great part, or altogether identical with those that now inhabit neighbouring seas; and these organic remains occur in such a manner, that it is plain they lived and died on the spots where they lie, ere those parts of the sea-bottom were elevated. 3rd. Experience shows that certain volcanic regions subject to earthquakes are often areas of elevation.

During long periods of depression strata may accumulate to an immense thickness under favourable conditions of supply; and time being also allowed for consolidation, when these are again unheaved they will, both as regards quantity and structure, be more apt to resist destruction than smaller masses of strata that were formed during periods of minor oscillations of sea and land. Nevertheless, we must not conclude that great thicknesses of strata necessarily imply a great length of time for their formation, nor, on the other hand, that comparatively thin strata have been rapidly formed. It is mainly a question of the amount of sediment transported to the area under consideration. Deep-sea formations are slowly formed, and a few feet of such strata may equal in time many thousands of feet of deposits formed near the shore.

Strata are consolidated chiefly by the pressure of overlying deposits and by chemical infiltrations. Some formations are many thousands of feet in thickness. In a set of strata 10,000 feet thick, if the whole weight bore vertically downwards, it would be immense; but besides this, more intense pressures have taken place throughout all but the

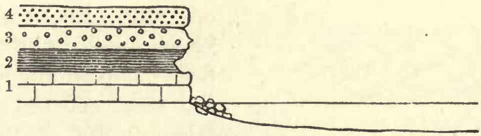


FIG. 2.—SECTION OF STRATIFIED ROCKS IN A SEA-CLIFF.

very latest geological epochs. This kind of pressure has been brought about by contraction of the earth's crust, due to radiation of the proper heat of our globe into space, the result being, that over broad areas rocky masses have been much contorted and compressed, and thus mountain ranges have been upheaved.

If we examine the stratified rocks that form the land, we very soon discover that a large proportion of them are arranged in thin layers or thicker bands or beds of *shale*, *sandstone*, *conglomerate*, and *limestone*, more or less pure; for shales are sometimes sandy, sandstones sometimes shaly, and most conglomerates have a sandy and sometimes a shaly or marly base in which the pebbles are embedded, while limestones occur of every degree of impurity. These, with the exception of certain limestones, must have been formed in a manner analogous to that before described, proving that such beds have been deposited as sediments from water. Take, for instance, a possible cliff by the sea-shore, and we shall perhaps find that it is made of strata, which may be horizontal, as in Fig. 2, or inclined, as in Fig. 3, or even bent and contorted, as in Fig. 4. If, as in the diagram, Fig. 2, we take a particular bed, No. 1, we may learn that it consists of strata of limestone lying one upon another. Bed No. 2 may be of shale, arranged in thin layers, more regularly than in No. 1. No. 3 may consist of pebbly materials, arranged in ruder layers, for, the material being coarse, the bedding may be irregular, or even quite indistinct. Then in No. 4, the next and highest deposit, we may have a mass of sandstone, arranged in definite beds. These various strata in the aggregate form one cliff. Rocks of these kinds, singly, or interstratified, compose the bulk of the strata of the British Islands; and it must be remembered that these were, for the most part, originally loose stratified sediments, piled on each other often to enormous thicknesses, and subsequently consolidated by pressure and chemical action. In some cases after consolidation, they have been so much altered by heat and other agents of metamorphism, as to have lost almost all signs of their original stratification; sometimes they are undisturbed, except by mere upheaval above the sea; in other cases the beds have been rucked up or contorted, in the manner shown in Fig. 4.

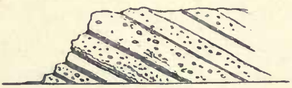


FIG. 3.—INCLINED STRATA.

Some formations, such as great part of the Silurian and older rocks of Wales and its neighbourhood, consist essentially of deposits that were originally marine mud and sand, accumulated bed upon bed, intercalated here and there with strata of limestone, the whole being many thousands of feet in thickness. These have since been hardened into rock. Others, like the Old Red Sandstone, were originally spread out in alternating beds of mud, sand, and pebbly banks, generally coloured red by peroxide of iron. Some, again, like the Liassic and Oolitic deposits, were formed of alternating strata of clay, sand, and limestone; while others, like the greater masses of the Carboniferous Limestone and the Chalk, were formed almost wholly of calcareous mud, and of remains of calcareous organisms.

When we examine such rocks in detail, we often find that they contain *fossils* of various kinds—shells, corals, sea-urchins, encrinites or sea-lilies, crustaceans, such as crabs and trilobites, the bones, teeth, and scales of fishes, land plants, and, more rarely, the bones of terrestrial animals. For instance, in the bed of sandstone, No. 4

FIG. 4.—CONTORTED STRATA.

(Fig. 2), we might find that there are remains of sea-shells; occasionally—but more rarely—similar bodies might occur in the conglomerate, No. 3; frequently they might lie between the thin layers of shale in No. 2; and it is equally common to find large quantities of shells, corals, sea-urchins, encrinites, and various other forms of life in such limestones as No. 1, which, in many cases, are almost wholly composed of entire or broken shells and other marine organic remains.

Considering the number of creatures that inhabit the waters of sea or lake, it is easy to understand how numerous shells and other organic remains have thus been buried in the sediments, the component grains of which, large or small, have been borne from the land into water, there by force of gravitation to arrange themselves as strata. By the occurrence of shells in these sediments, and by the decay of the limy structures of various organisms, it is easy to understand why the rocks so often are more or less *calcareous*. The question, however, arises, how it happens that thick strata of pure or nearly pure carbonate of lime, or limestone, have been formed.

Though the materials of shale (once mud), sandstone (once loose sand), and conglomerate (once loose stones and pebbles), have been carried from the land into the water, and there arranged as strata; and though limestones have, often to a great extent, been also mechanically arranged; yet it happens with comparative rarity that quantities of fine unmixed calcareous sediment have been carried by rivers to the sea. Such sediment has sometimes been directly derived from the waste of sea-cliffs or coral-reefs, and mixed with other marine sediments. When, however, it so happens that we get a mass of limestone consisting almost entirely of shells, corals, and other hard parts of creatures that lived in the sea, in estuaries, or in lakes, the conclusion is forced upon us that, be the limestone ever so thick, it has been formed by the life and death of animals that lived in water. In many a formation—for instance, in some of the layers of the Carboniferous Limestone—the eye tells us that they are formed perhaps entirely of fragments of encrinites, or of shells and corals, of various kinds, or of all these mixed together; and in other cases where the limestone is homogeneous, the microscope reveals that it is largely made of foraminifera, or of exceedingly small particles of other organic remains. Even when these fragments are indistinguishable to the naked eye, reflection tells us that such marine limestone-deposits must have been built up from the débris of organisms, for there is no reason to believe that vast formations of limestone, extending over hundreds of square miles, are now, or ever have been precipitated in the open ocean by inorganic chemical processes unaided by any organic agents. It sometimes happens, indeed, that gradual accumulations of such beds of limestone have attained several hundreds of feet of vertical thickness in what belongs to recent times in a geological sense—as, for example, in the great coral-reefs of the Pacific Ocean, and perhaps, though in less known degree, in the calcareous and foraminiferous ooze of that ocean and of the Atlantic.

Whence comes the carbonate of lime by which these animals make their skeletons ? If we analyse the waters of springs and rivers, we discover that many of them consist of water that is more or less hard—that is to say, not pure, like rain-water, but containing salts of lime in solution. Thus, the rain-water that falls upon the land percolates the rocks, and, issuing again in springs, carries with it not only salts of soda, potash, iron, &c., but, if the rocks be calcareous, large quantities of bicarbonate of lime in solution. The reason of this is, that all rain in descending through the air takes from it a certain amount of carbonic acid ; and this acid has the power of dissolving the carbonate of lime which enters into the composition of so many stratified rocks. In this way it happens that springs are often charged with lime, in the form of a soluble bicarbonate, which is carried by rivers into lakes and estuaries, and, finding its way to the sea, affords material to mollusca and other marine animals to make their shells and bones. Thus, little by little, lime is abstracted from sea-water to form parts of animals, which, dying in clear water, frequently produce by their calcareous remains strata of nearly pure limestone. Some of this may be consolidated into rock almost as fast as it is formed.

What is going on now has been going on throughout all known geological time, from that of the deposition of the oldest fossiliferous rocks down to the present day.

Igneous rocks form a much smaller proportion of the surface-rocks of most parts of the world, though in certain areas, such as Iceland, the Faroe Islands, the Deccan, Abyssinia, and throughout certain areas of the Western

United States, they largely predominate. To take Britain as an example: in North Wales a considerable proportion of the rocks of Lower Silurian age are formed of igneous masses. In Cumberland a very large part of the Lower Silurian rocks are igneous, while a comparatively small proportion of igneous rocks is found among the Silurian rocks of the mainland of Scotland. Even the large masses of granite there, occupy but small areas when compared with the great extent of ordinary stratified and metamorphic rocks amid which they lie. It is chiefly in the Inner Hebrides that great masses of Tertiary volcanic rocks occur. Igneous rocks exist in smaller proportions in Northumberland, Devon, and Cornwall, the more important being the bosses of granite on Dartmoor, and at the Land's End. If, however, we examine the midland, southern, and eastern parts of England, we shall find hardly any igneous rocks whatever, except in the small area of Charnwood Forest, where Palæozoic rocks rise in places from beneath the Secondary strata.

I have now briefly to indicate how we are able to distinguish igneous from aqueous rocks, in countries where there are neither active volcanoes nor extinct craters, such as those of Auvergne and the Eifel.

In a general way we can distinguish them from strata formed by aqueous deposition because many of them are *unstratified*, and have other external and internal structures different from those of aqueous deposits. To take examples: If we examine the lavas that flowed from any existing volcano, and have afterwards consolidated, we find that they are frequently vesicular. This vesicular structure is largely due to watery vapour, and partly to gases ejected along with the melted matter, which, expanding in their efforts to escape from the melted lava, form a number of vesicles, just as yeast does in bread. We see the same features in iron-furnaces, in some of the slags, which, indeed, are simply artificial lavas. This peculiar vesicular structure is never found in ordinary stratified rocks. Here, then, experience tells that modern rocks with this structure were formed by igneous agency; and this in ancient cases is not the less certain though the vesicles have since been filled by the infiltration and deposition of mineral matters in solution, such as carbonate of lime, zeolites, and silica. Such igneous rocks, which contain these almond-shaped cavities filled with crystalline matter, are called *amygdaloids* ; and it has not infrequently happened that on the surfaces of old masses of rock, the kernels, say of carbonate of lime, have been dissolved out by the influence of rain-water bearing carbonic acid, and the surface has regained its original vesicular appearance.

Experience also tells us that some modern lavas are crystalline—that is to say, in cooling, their constituents, according to their chemical affinities, have crystallised in distinct minerals such as augite, various felspars, &c. When we meet with similar, even though not identical crystalline rocks, such as porphyrites, trachytes, basalts, and dolerites, associated with our strata, we are entitled to consider them as having had an igneous origin.

In modern volcanic regions, such as Iceland, and in Tertiary regions dotted with extinct volcanoes, as in the Eifel and Auvergne, where the forms of the craters still remain, the lavas are often columnar; and when we meet with columnar and crystalline rock-masses of Silurian, Carboniferous, or of any other geological age, we may fairly assume that such rocks are of igneous origin. Modern lavas have often a vitreous or glassy structure, such as obsidian, which its ancient analogue pitchstone closely resembles. Others possess a slaggy structure, and are sometimes formed of wavy ribboned layers that indicate a state of viscous flowing, similar to the contorted ribbon-like structure found in various slags. Iron-slag is formed of the silica and alumina of the iron ore and its flux of lime, melted together and still retaining a percentage of iron. Ancient lavas, such as those of Snowdon, of Lower Silurian age, often still possess a slaggy and ribboned structure.

Further, igneous rocks are apt to alter any strata through which they are ejected or over which they flow. Accordingly, in rocks of all ages, and rising nearly vertically (as in Fig. 5), we may find *dykes* (1), from which *veins* (2) have been injected among the strata, and ultimately the dyke may terminate in an overflow of lava (3), that may be columnar. When sheets of eruptive rock extend for some distance between the planes of bedding, they are called *sills*; but these intrusive sheets, though sometimes nearly horizontal and apparently conformable with the strata, are found here and there to occupy different positions among the strata. (See Fig. 6.) In such cases the stratified rocks are apt to be altered for a few inches or even for several feet at their junction with the igneous rocks. If shales, they may be hardened or baked into a kind of porcellanic substance, jasper, or lydian-stone; if sandstones, they may be turned into quartzite, something like the sandstone floor of an iron-furnace that has long been exposed to intense heat.

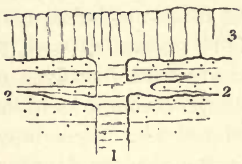


Fig. 5.—Dyke and Veins of Igneous Rock.

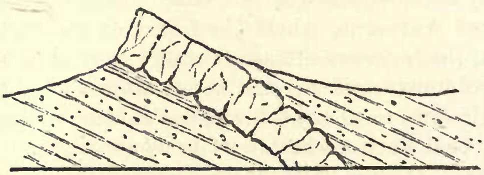


Fig. 6.—Sill or Intrusive Sheet of Igneous Rock in Sedimentary Strata. (J. G.)

From these and many other circumstances, the geologist finds no difficulty in deciding that such and such rocks are of igneous origin, or have been melted by heat. The crystalline structure identical with or similar to some modern lavas, the occasional columnar structure, the slaggy ribboned, and vesicular structures, the penetration of strata by dykes, veins, and sills, and the alteration of the stratified rocks at the planes of contact, all prove the point.

Modern volcanic ashes are simply fragments, small and large, of lava ground often to powder in the crater by the rise and fall of the steam-driven rocky material. These are finally ejected by the expansive force of steam, and with the liberated vapour, volcanic dust, lapilli, and blocks of stone, are shot sometimes thousands of feet into the air mingled with watery vapour, which condensing in the higher atmosphere, falls with the ashes on the sides of the volcanic cone in heavy showers of rain. By the study of modern volcanic ashes, it is not difficult to distinguish those of ancient date, even though they have become consolidated into hard and more or less stratified rocks. Their occasional tufaceous character, the broken crystals, the imbedded slaggy-looking fragments of rocks and bombs, and sometimes the occurrence of coarse volcanic agglomerates, every fragment of which consists of broken lava, all help in the decision. In fact, tracing back, from modern to ancient volcanoes, step by step through the various formations, the origin of ancient volcanic rocks is clear; and further, it leads to similar conclusions with respect to the igneous origin of bosses of crystalline rocks, such as granite, syenite, and diorite, which, having been melted and cooled deep in the earth, were not ejected, and never saw the light till they were exposed by denudation.

CHAPTER II.

THE DIFFERENT AGES OF STRATIFIED FORMATIONS: THEIR SUCCESSIVE DEPOSITION.

We have now to consider the different ages of stratified rocks; and the diagram, Fig. 2, p. 9, will help to make this clear. There the lowest bed, No. 1, must be the oldest, because it was deposited in the sea (or other water) before bed No. 2 was spread above it as layers of mud, and so on to 3 and 4—taking the strata in order of upward succession. Now, if we had never found any fossil remains imbedded in the rocks, we should lose half the interest of this investigation, and our discovery, that rocks are of different ages, would have only a minor value. Turn again to the diagram. We find at the base, beds of limestone, No. 1, perhaps composed of corals and shells. The organic remains in the upper part of these beds lie above those in the lower part, and therefore the latter were dead and buried, before the once living shells which lie in the upper part inhabited the area. Above the limestone there are beds of shale, No. 2, succeeded by No. 3, a conglomerate, and then comes the bed of sandstone, No. 4; therefore the shells (if any) in the shale, No. 2, are of younger date than those in the limestone, No. 1; the organic remains, plants or animals as the case may be, in the conglomerate, No. 3, were buried among the pebbles at a later date than the shells in the shale, and the remains of life in the sandstone, No. 4, were latest of all. The fossils found in each successive bed had lived and died before the sediment began to be deposited that forms the bed above. All these strata, therefore, contain relics of ancient life of different dates, each bed being younger or older than the others, according as we read the record from below or from above. It is evident that the same kind of reasoning is equally applicable to the inclined strata of Fig. 3, or to the contorted beds of Fig. 4.

On many a coast, where the cliffs consist of stratified rocks, a lesson may easily be learnt on the order, or comparative dates of deposition of geological formations. The Liassic, Oolitic, and Cretaceous cliffs of Yorkshire, from the Tees to Flamborough Head, form excellent examples; still better is the coast of Devonshire and Dorsetshire, from Torquay to Portland Bill. Let us take part of the latter as an example, from Axmouth, near Lyme Regis, to the Dorsetshire hills, north of Weymouth.

If we eliminate those displacements of the strata called *faults*, we there find a succession of formations arranged somewhat in the manner shown in Fig. 7. The horizontal line at the base represents the shore-line. On the west (1) represents red marly strata, known as the New Red or Keuper Marls. These pass under black shales and thin beds of white fossiliferous limestone (2), known as the Rhætic Beds. These in their turn pass or *dip* under thick beds of blue limestone and clay, called Lower Lias (3), which are seen to dip under the sandy clays and rock-bed of the Marlstone or Middle Lias (4), overlaid by the sandy shales of the Upper Lias (5), on which rest the sand and limestone of the Inferior Oolite Series (6), followed by the Fuller's Earth formation (7). Next comes a series of strata (8), consisting of shales and shelly limestones, and

Fig. 7.—Diagram-section from Axmouth to near Weymouth.

known as the Forest Marble and Cornbrash. These dip under the Oxford Clay (9), which passes under the sands and limestones grouped as Corallian (10), and still going eastward we come upon the Kimeridge Clay (11), which, in its turn, passes under the clays, sands, and limestones of the Portland and Purbeck Beds (12). Above all comes the Cretaceous Series of this district, consisting of Gault and Upper Greensand (13), and Chalk (14) which in a bold escarpment overlooks the vale of Kimeridge Clay near Portisham.

Here, then, we see a marked succession of strata of different kinds, or having different *lithological characters*, formed of marls, clays, sands, and limestones, alternating with each other. They are all sediments originally deposited in the sea (if we except the New Red Marl, which was deposited in a salt lake). Some are only forty or fifty feet, others are more than five or six hundred feet thick.

If we leave the coast-cliffs and turn to the middle of England—from the borders of South Staffordshire and Warwickshire to the neighbourhood of London—we discover that the land is made of strata, arranged in successive stages more or less in the manner already described, and consisting of similar materials. Thus, through Warwickshire and South Staffordshire, we have rocks formed of New Red Sandstone. The Red Sandstone dips to the east or south-east, and is overlaid by New Red Marl; the Red Marl dips under beds of shale, blue limestone, clay, and brown marlstone, forming the various divisions of the Rhætic Beds and Lias; these pass under a great succession of limestones and clays, known as the Oolites; these, in their turn, are overlaid by beds of sand, clay, and limestone, named the Cretaceous Series; which again, in their turn, dip under the Tertiary clays and sands of the London Basin. All these pass fairly under each other in the order thus enumerated. Experience has proved this, for though there are occasional interruptions in the completeness of the series, some of the formations being absent in places, yet the order of succession is never inverted, except where, by what may be called geological accidents, in some parts of the world, great disturbances have locally produced forcible *inversions* of some of the strata. Such is often the case on the flanks of mountain chains. Researches made in recent years have shown that *inversions* are due not only to inverted folds in the strata, but to oblique or more or less horizontal faulting that sometimes follows the over-folding (see Fig. 8). In the north-west Highlands there is evidence of many remarkable *thrust-planes*, whereby older rocks have been forced over newer strata. On a smaller scale, there is also evidence of a 'thrust-fault' or 'overlap-fault' in the

Fig. 8.—Diagram of a Reversed Fault. (J. G.)

Somerset Coal-field. By this disturbance, which has been described by Mr. J. McMurtrie, portions of the Coal-measures have been forced over the same set of beds from south to north, for a distance of from 120 to 230 yards.

Observation of the surface in cliffs, railway-cuttings, and quarries, however, proves the general succession of formations, and so does experience in sinking deep wells and mine-shafts. If, for example, in parts of the midland counties we sink through the Lower Lias, we pass into the New Red Marl; if we pierce the Red Marl, we reach the water-bearing strata of the New Red Sandstone. If in certain districts we penetrate the Cretaceous strata, we may reach the Upper Oolites, and under London many deep wells have been sunk through the Eocene Beds, in the certainty of reaching the Chalk and with little doubt of finding water.

Therefore, not only the surface of the land is very largely formed of various stratified rocks, but the several formations dip or pass under each other in regular succession. We see, in fact, vast beds placed much in the same way as sheets of variously coloured pasteboard, placed flat on each other, and then slightly tilted up so as to slope in one direction, one edge of each sheet or formation being exposed at the surface along a belt of country that marks its *outcrop*.

Vertical sinkings, therefore, in horizontal or slightly inclined strata, often prove practically what we know theoretically, namely, the underground continuity in certain areas of strata one beneath the other. Accurate but more difficult observation and reasoning have done the same for more disturbed strata, so that our island and other countries have been proved to be formed of a series of beds of rock, some hundreds and some thousands of feet in thickness, arranged in succession, the lowest *stratified* formation being of older and the uppermost of younger age.

Most of these strata are fossiliferous, that is to say they contain shells, bones, and other relics of the creatures that lived and died in the waters or water-laid sediments of each special period; or as sometimes happens, they contain the remains of land-plants and terrestrial animals that have been washed into the sea or into lakes. What is the more special evidence on this subject afforded by the rocks? As we proceed, from west to east across the Secondary and Tertiary strata, and examine the fossils found in successive formations, we discover that they are not the same in all, and that most of them contain *marine* organic remains, which are in each formation of *species* and sometimes of *genera* more or less distinct from those in the formations immediately above or below. There are also a few fresh-water deposits, but the discussion of these is not essential to the present argument. Although our formations are characterised by certain groups of fossils, we have also to take into account the nature of the sediment in which the fossils are found—the old sea-floor on which the animals lived. In a limestone we should not expect to find the same fossils as in a shale.

Thus turning again to Fig. 7, p. 19, the Red Marl series No. 1, is rarely fossiliferous, and such fossils as these beds may contain are chiefly land-plants, footprints of Amphibia, and remains of Saurians. The Rhætic Beds 2, contain sea-shells of a few genera and species, the latter somewhat distinct from those found in the Lower Lias No. 3, where Ammonites and Belemnites appear; and so on, stage by stage, through the remaining strata of the Oolitic rocks, up to the Kimeridge Clay No. 11. Throughout the whole series there is generally enough of difference in the *species*, especially of the Ammonites, and of other characteristic forms to enable anyone with sufficient knowledge to tell by fossils alone what formation he may chance to be examining. When, still ascending in the series, we come to the Portland and Purbeck Beds 12, we find that in them we have evidence of a considerable change of conditions from marine to freshwater and estuarine beds. Again, in the Cretaceous formations represented by 13 and 14, a wonderful change takes place. None of the Oolitic species pass into these formations, and some of the genera, especially of Cephalopoda, are new. As we proceed to study still later formations we find the fossils to approximate in genera, and finally in species, more and more closely to the forms of life now living. There is thus not only a succession of formations, but also of organic remains. In the older rocks only lowly types of life are found; in each succeeding formation we notice the incoming of more highly organised remains, of Fishes, Saurians, Mammals, and lastly of Man himself.

The above instances afford a good type of the kind of phenomena that occur again and again throughout the geological series in this country and elsewhere. After a minute examination, therefore, of the stratigraphical structure of our island, the result is, that geologists are able to recognise and place all the formations in serial order, so as to show which were formed first and which were formed latest, as noted in the table, p. 47.

CHAPTER III.

DENUDATION, SYNCLINAL AND ANTICLINAL CURVES, FAULTS, AND UNCONFORMITIES.

It is needful now to explain the meaning of a few terms which are used very frequently.

Denudation, in the geological sense of the word, means the stripping away of rocks from the surface, so as to expose other rocks that lay concealed beneath them.

Running water wears away the ground over which it passes, and carries away detrital matter, such as loose pieces of rock, pebbles, sand, and mud; and if this goes on long enough over large areas, there is no reason why any amount of matter should not in time be removed. For instance, in North America we have a notable case of denudation, now being effected by the river Niagara, which, below the Falls, has cut a deep channel through the rocks, about seven miles in length. The proofs are perfect that the Falls originally began at the great escarpment at the lower end of what is now this gorge; that the river, falling over this ancient cliff, has by degrees worn for itself a channel backwards, from two to three hundred feet deep, and from two to four hundred yards wide, through strata that on either side of the gorge once formed a continuous plateau.

This instance shows the kind of denudation produced by running water. At one time the channel did not exist. The river has cut it out, and in so doing, strata—some of them formerly more than two hundred feet beneath the surface—have been exposed by denudation. Calculations, based on the rate of waste during the past 150 years, show that to form this gorge a period of nearly fifty thousand years would have been required.

Now refer to Fig. 9, and suppose that we have different strata, 1, 2, 3, and 4, lying horizontally one above the other, together forming a mass several hundreds of feet in thickness. The running water of a brook or river by degrees wore away the rocks more in one place than another, so that the strata 3, 2, and 1, were successively cut into and exposed at the surface, and in time a valley is formed. This is the result of denudation.

The strata that form the outer part of the Earth's crust have, in many places, been thrown into *anticlinal* and *synclinal* curves. A synclinal curve means that the curved

Fig. 9.—Section across a Valley.

strata are bent downwards as in 1, Fig. 10; an anticlinal curve that they bend upwards as in 2. The whole were originally deposited horizontally, consolidated into rock, and afterwards bent and contorted. The strata marked × may perfectly correspond in all respects in their structure and fossils, and as in hundreds of similar cases, it is certain that they were once joined as horizontal strata, and afterwards thrown into anticlinal and synclinal curves. The strata indicated by dotted lines (and all above) have been removed by *denudation*, and the present surface is the result.

Chemical action is another agent that promotes waste or denudation. Thus rain water, charged with carbonic acid, falling on limestone rocks such as the Carboniferous Limestone, or the Chalk, not only wears away part of these rocks by mechanical action, but also dissolves the carbonate of lime and carries it off in solution as a bicarbonate, leaving often a residue of red earth, and other insoluble material. This fact is proved by numbers of unworn flints, that have sometimes accumulated to several feet in thickness, on the surface of the table-land of Chalk.

Degradation of the rocks of many regions is also powerfully affected by occasional landslips. The waste thus produced is seen on a large scale in many of the Yorkshire valleys, where Carboniferous sandstones and shales are interstratified, and vast shattered ruins of sandstone cumber the sides of the hills and the bottoms of the valleys in wild confusion (Fig. 118).

The constant atmospheric disintegration of cliffs, and the beating of the waves on the shore, often aided by land-

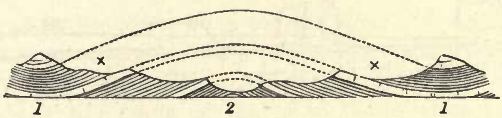


FIG. 10.—SECTION SHOWING ANTICLINAL AND SYNCLINAL STRUCTURES.

1. Synclinal curves. 2. Anticlinal curve.

slips, are other modes by which watery action denudes and cuts back rocks. This has been already mentioned. Caverns, bays, and other indentations of the coast, needle-shaped rocks or stacks standing out in the sea or on the foreshore, from the main mass of a cliff, are all caused or aided by the long-continued wasting power of the sea, which first helps to destroy the land and then spreads the ruins in new strata over its floor. The formation of these sea-stacks and of arches is aided by joints and fissures in the rocks (see Fig. 11).

When we consider that, over and over again, strata thousands of square miles in extent, and thousands of feet in thickness, have been formed by the waste of older rocks, equal in extent and bulk to the strata formed by their waste, we begin to get an idea of the greatness of this power of denudation. A notable example on a grand scale may be seen in the coal-fields of South Wales, of Bristol, and of the Forest of Dean. These three coal-fields were once united, but those of South Wales and Dean Forest are now about twenty-five miles apart, while the Bristol and Somersetshire coal-field is separated from both by the estuary of the Severn. These separations have been brought about by the agency of long-continued denudations, which have swept away thousands of feet of strata that had been bent into anticlinal and synclinal curves in the manner shown at × in Fig. 10, p. 27, and Fig. 38.

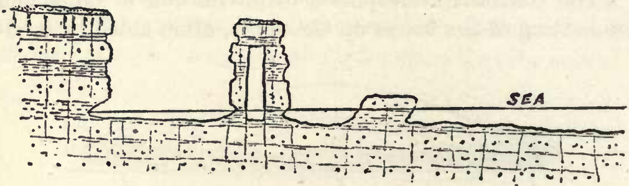


Fig. 11.—Formation of Stacks and Arches in Rocks on the Sea-coast. (J. G.)

The small coal-field of the Forest of Dean has thus become an *outlier* of the great South Wales coal-field: it is a mass of coal-measures resting on older Carboniferous rocks. The hills at either end of the section, Fig. 10, are outliers; while the term *inlier* is applied to formations that appear at the surface and are bordered by newer strata, as at No. 2 in the same section.

Thus we come to the conclusion that the greater portion of the rocky masses of our island have been arranged and re-arranged under slow processes of the denudation of old, and the reconstruction of newer strata, extending over periods that seem to our finite minds almost to stretch into infinity.

Disturbances in the earth's crust are frequently attended by faults. A *fault* is a dislocation accompanied by displacement, so that strata which were originally continuous have been shifted down or up, as the case may be, on one side or the other (see Fig. 12). Here the strata are faulted with a downthrow to the left hand; and the downthrow is usually on that side of the slope or *hade* of the fault, the exceptions being termed reversed faults. Where

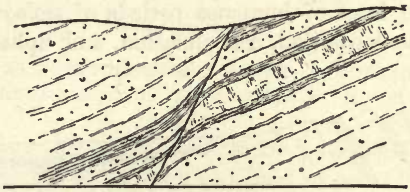


Fig. 12.—Section showing Fault in the Strata. (J. G.)

several faults occur there may be successive downthrows, producing what are called *step faults*; and these may be modified by wedge-like masses of strata being let down alongside the plane of the main faults, thus producing what are known as *trough faults*. Both these features are

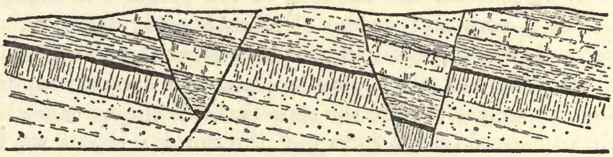


Fig. 13.—Section showing Step and Trough Faults. (J. G.)

shown in the accompanying section (Fig. 13). A diagram of a reversed fault has been already given (p. 21).

Unconformable stratification, when its significance has been realised by the student, cannot fail at once to impress on the mind a sense of the degradation of strata in some old epoch similar to that which is now going on, and few objects speak more eloquently of *geological time*. In the following diagram (Fig. 14) No. 1 represents an old land-surface, in which perhaps beds of sandstone and slate or shale have been upheaved at a high angle. Let us then suppose that, by the wasting power of weather and sea, the strata No. 2 have been won from that old land and deposited on the upturned and denuded edges of the strata No. 1. This constitutes a case of *unconformity*, and it marks the lapse of immense periods of *geological time*—first by the deposition, consolidation, and upheaval of the

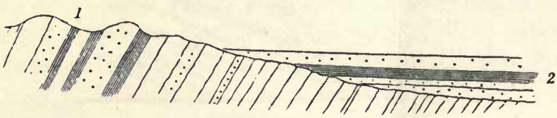


FIG. 14.—SECTION SHOWING UNCONFORMITY.

2. Later beds lying unconformably upon the older strata. 1. Old disturbed strata.

strata No. 1, and secondly in the deposition of the strata No. 2, which were made from the waste of No. 1.

There are many cases of this kind of unconformity extending through all geological time. If, in addition to this, we consider the meaning of the progressive changes in the genera and species of animals and plants, as we proceed from the older to the newer formations, it becomes obvious, that as yet we have no means of even attempting to form a clear idea of the time that has elapsed since life first appeared on the surface of the world, nor can we fix any dates in years for the ages of our geological formations.

CHAPTER IV.

IGNEOUS AND METAMORPHIC ROCKS, SHRINKAGE AND DISTURBANCE OF THE EARTH'S CRUST.

I HAVE already explained that rocks are divided into two great classes—those of aqueous and those of igneous origin; and that aqueous rocks may generally be known by their stratification and by the circumstance that a great many of them contain relics of marine and freshwater life, in the shape of fossil shells and other kinds of organic remains. The materials also of which these beds are composed generally show signs of having been deposited in water, the coarser particles being rounded by the action of the waves of the sea, or by the running waters of rivers.

The other rocks, classed as igneous, are associated in different localities with the formations named in the table (p. 47).[1] Some of these igneous rocks consist of contemporaneous beds of volcanic ash, or old lavas; others consist of matter intruded among the strata from below. Rocks that have been melted are known to be igneous by their crystalline, slaggy, scoriaceous, vesicular, or columnar structures, and also by the effects which some have produced on the strata with which they are associated. Shales, sandstones, &c., are often hardened, bleached, and even vitrified at the points of junction with dykes of greenstone or basalt, or with old lava beds (Fig. 15); and

[1] For an account of the Volcanic History of Britain, see Sir A. Geikie, *Addresses to Geol. Soc.*, 1891–92.

alteration takes place on a greater scale when large masses of igneous rock have been intruded among the strata.

Then by comparing volcanic rocks of old date with those of modern origin, we are able to decide with perfect truth, that rocks which were melted long before the human race appeared upon the world are yet of truly igneous origin.[1]

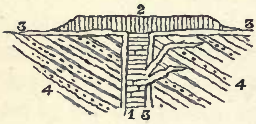


FIG. 15.—SECTION OF ERUPTIVE ROCKS.

4. Unaltered sandstone and shale.
3. Altered strata at junction.
2. Overflow of basaltic lava.
1. Dyke with veins.

Changes of a more general character are especially marked in cases where granite, syenite, quartz-porphyries and their allies, are associated with stratified deposits. Their igneous affinities are known by their crystalline structure, their modes of occurrence, and the effects they produce on the strata. Granite is composed of crystals of quartz, felspar, and mica; and syenite mainly of felspar and hornblende.

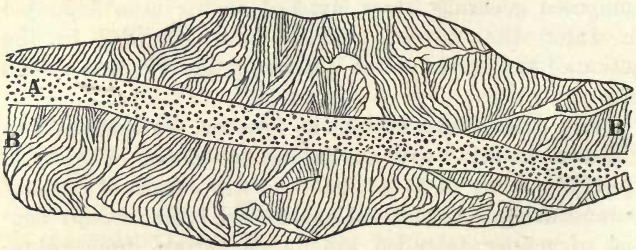


FIG. 16.—VEIN OF GRANITE AT BRODICK MILL-DAM, GOATFELL, ARRAN.[2]

A, vein of granite; B, contorted mica-schist. The ramifying white spaces are white quartz.

They often send veins or dykes into stratified rocks with which they are in contact, as in Figs. 16 and

[1] For a full account of igneous rocks, see J. J. H. Teall, *British Petrography*, 1888; see also J. W. Judd, *Volcanoes*, ed. 2, 1881.

[2] Ramsay, *Geology of the Island of Arran*, 1841, p. 4.

17, and frequently all along the line of junction, and often at great distances from it, alterations of the strata of an extreme character (*metamorphism*) are common. One marked distinction between granitic and ordinary volcanic rocks is, that though injected veins of granite are common, granitic rocks never rose to the surface in a melted state, and overflowed like lava streams. Certain peculiarities of crystallisation showing the presence of saline water in minute cavities of their quartz-crystals, prove the granitic rocks to have cooled and consolidated under very great pressure and at vast depths beneath the surface. Recent researches tend to show that in the consolidation of molten masses, different minerals successively crystallise, the earlier crystals being often of a basic character. Differences may also have originated in the mass by the separation of some constituents by gravity. In ordinary granite the quartz may occupy irregular interspaces after the mica and felspar had crystallised. In granophyre, and sometimes in pegmatite or graphic granite, the quartz and felspar crystallised simultaneously.

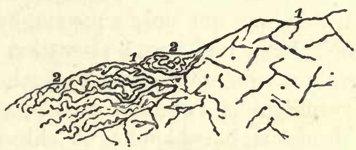


FIG. 17.—SECTION OF GNEISS AND GRANITE.

1. Granitic mass with injected veins among (2) Gneissic rocks.

A third division, or sub-class, is known as *metamorphic rocks*. All strata as they assume a solid form become to a certain extent altered; for originally many of them were soft or loose sediments of calcareous mud, clay, sand, and gravel, or mixtures of these. When these were accumulated, bed upon bed, till thousands of feet were piled one upon the other, then, by intense and long-continued pressure, sometimes by heat, and by chemical changes that took place in consequence of infiltrations among the strata themselves, they became changed by degrees into hard masses of limestone, shale, sandstone, or conglomerate, as the case may be. These have not always remained in the condition in which they were originally consolidated, for it has often happened that disturbances of a powerful kind took place, and strata originally flat have been bent into every possible curve. Still further changes have in many instances taken place; and when these have produced a marked effect on the mineral structure of the rock, it is said to be *metamorphosed.* Under such circumstances the fossils in the sedimentary rocks may become wholly obliterated.

As a general rule highly metamorphosed rocks occur in regions where the strata have been greatly disturbed; and they owe their characters partly to the effects of great earth movements, partly to contact with molten igneous matter. In this way not only aqueous, but also many old igneous rocks have undergone alteration; known as regional and contact metamorphism. Such rocks, when the metamorphism is extreme, consist of gneiss, which may be micaceous, hornblendic, or chloritic; and of mica-schist, chlorite-schist, talc-schist, hornblende-rock, crystalline limestone, quartzite, and a number of others. Thus by contact with molten rock the calcareous beds may become crystalline limestone, and the sandstone may be changed into quartzite, which is no longer hewable like ordinary sandstone, but breaks with a hard and splintery fracture. In other cases changes of a somewhat different kind affect the stratified rocks, for new minerals have been developed. Clay-slates are simply clays consolidated by pressure, and affected by a rough cleavage; they pass into true slates. Approaching granites ordinary slates often assume a foliated structure by the development of distinct minerals, such as chiastolite and mica; and thus pass into a chiastolite-slate or into a mica-schist.

Gneiss itself is a coarse crystalline schist, formed ordinarily of irregular leaves or folia of mica, quartz, and felspar. Its constituents being arranged in rudely crystalline layers give the rock a banded appearance; and having perhaps the same general composition as granite, it is sometimes spoken of as a foliated granite. Indeed it is often impossible to draw any definite line between gneiss and granite, for they pass into each other by insensible gradations. There are nevertheless many varieties of gneiss ; some containing hornblende and augite, and being allied in mineral composition to diorite, gabbro, or syenite. All, however, exhibit the characteristic foliated or banded arrangement of the different minerals.

The distinct minerals that are developed in various crystalline schists, minerals such as hornblende, schorl, garnet, staurolite, chiastolite, mica, &c., were not new substances introduced by contact with granite, or other rock, but were in most instances developed under the influence of metamorphism from materials that previously existed in the rocks before their metamorphism began ; and these changes were aided by hydrothermal action due to the presence of heated alkaline waters deep beneath the surface of the earth. Through some process, in which heat played a large part, the rock having been softened, and water—present in most rocks or in fissures underground—having been diffused throughout the mass and heated, chemical action was set up, and the substances that composed the rocks were enabled more or less to re-arrange themselves according to their chemical affinities ; and thus distinct minerals were developed from elements present in the original rocks, or in the thermal waters which permeated them. In the slaty schistose rocks the minerals seem to have found facilities for their development in pre-existing planes, whether of bedding or of cleavage ; or, in other words, if the rocks be uncleaved when metamorphism occurs, the foliated planes show a tendency to coincide with those of bedding ; but if intense cleavage has preceded, the foliation will generally follow the planes of cleavage. In some cases where metamorphic slates or schists seem to show gradations into gneiss, such appearances have been caused by the forcing of thin veins of granite along the planes of schistosity (see Fig. 17, p. 33): in other cases it is most difficult to separate very highly altered sedimentary rocks from some varieties of gneiss.

Sedimentary rocks, however, like the Bovey Beds in Devonshire, are sometimes very largely made up of decomposed granite, and when the rocks are most highly metamorphosed, so as to have been thoroughly melted, the entire re-arrangement of constituents is easy to understand. From the fact that gneiss passes into granite, and that some forms of gneiss appear to be products of the metamorphism of sedimentary rocks, it may be that granite is sometimes merely gneiss still further metamorphosed by heat in the presence of moisture. Such transformations may have taken place; but when stratified rocks once became liquefied, they would be to all intents and purposes igneous rocks, just as much as the Bovey sands and clays, derived from the Dartmoor granite, are aqueous rocks.

The banding or foliation of gneiss was perhaps in the main produced by segregation, or the separation of the different minerals when the mass was in a plastic condition. Such features may have attended the original cooling of portions of the earth's crust. In other instances the re-arrangement of mineral matter has been due to the deformation caused by the mechanical agencies of disturbance, and in this way gneiss very largely originated from the crushing and metamorphism of masses of granite, and also of syenite, diorite, or gabbro. The whole subject is a very complex one, but we find that while in some cases the minerals retain their ordinary characteristics, and the rock has been subjected only to molecular re-arrangement, in other cases the minerals have been so acted upon by shearing processes which accompanied the crust-movements, that large crystals of quartz or felspar have been drawn out in an 'eye-like' form so as to produce what is known as *Augengneiss*. Sir Archibald Geikie has suggested that these parallel structures may, in some cases, really represent traces of movements in the original unconsolidated igneous masses, not wholly effaced by later mechanical stresses. The intensity in many countries of this metamorphism, extending over many thousands of square miles (as in Scotland, Norway, Sweden, and Canada), and through rocks thousands of feet in thickness, proves that it was the result of a long-continued process, taking place probably in all cases at considerable depths. The whole has then been upheaved and disturbed, often many times, and after denudation the gneissic and granitic rocks were at length exposed at the surface.

Serpentine is not uncommon in areas that have undergone some metamorphism. It is a magnesian silicate, containing iron-salts, and occurs both as a mineral in veins, and as a rock, associated with steatite. The green and red varieties seen at the Lizard in Cornwall are well known; the rock occurs also in Anglesey, in Ayrshire, and at Portsoy, in Banffshire. In this form, as pointed out by Professor Bonney, it appears to be due to the alteration of intrusive masses of peridotite, and its somewhat varied composition is due to the character of the rocks, containing olivine and other minerals, from which it has been derived.

Some of the metamorphic rocks have been highly disturbed, and in the north occupy about one-half of Scotland. Most of this area includes, and lies north-west of, the Grampian mountains. Thus it frequently happens that the schistose layers of gneiss are bent, or rather minutely folded, in a great number of convolutions, so small that in a few yards of gneiss they may sometimes be counted by the hundred. Metamorphic rocks of this character, as well as granite, were by the old geologists called Primary or *Primitive*, and were considered to have been formed in the earliest stages of the world's history, because in those countries that were first geologically described, they were supposed to lie always at the base of the ordinary strata.

The old theory (so far true) was that the world at one time was in a state of perfect igneous fusion; but by-and-by, when it began to cool, the materials arranged themselves as distinct minerals, according to their different chemical affinities, and consolidated as granite. The surface of the great globe was thus composed entirely of crystalline material; and as cooling progressed, and water, by condensation, attempted to settle on the surface which still remained intensely heated, the water could not lie upon it, for it was constantly being evaporated into the atmosphere; but when the cooling became decided, and consolidation had been fairly established, the water was able to settle on the surface of the granite. Then the sea and atmospheric agents commenced their operations on the rocks that rose above the water-level. The detritus worn from the granite was spread over the sea-bottom; and thus the earliest sediments were formed.

From astronomical considerations it is indeed believed by many persons that the earth has been condensed from a nebulous state, and passing into an intensely heated or molten condition, by radiation into space at length cooled so far, that consolidation commenced at the surface. By degrees that surface has been gradually thickening and overlies a nucleus, that may still in great part be in a molten state. Whether or not rocks of a granitic character really formed the main portion of the primæval crust we are not in a position to say; though it has been conjectured that, in those earliest ages the atmosphere was densely loaded with vapours, and the atmospheric pressure at the surface must have been enormous.

To return to the supposed primitive age of granites in general, we learn from subsequent research that, although our oldest known rocks are of a granitic or gneissose character, yet we have granitic rocks of almost all ages in the geological scale. Thus in Scotland rocks of this character are not only of great antiquity, but are also connected with the volcanic phenomena of Tertiary times; again, in Devon and Cornwall we have intrusions of granite that have altered rocks of Devonian and Carboniferous ages. Moreover the formation of gneiss and of various schists, though for the most part of great antiquity, may occur from the metamorphism of igneous and sedimentary rocks of different ages. It is therefore perfectly well known to geologists that the term primitive, as applied to granite or even to gneiss, is no longer generally tenable.

I have already stated that regions occupied by metamorphic rocks are apt to be much contorted. There seems, in fact, to be an intimate connection between excessive disturbance of strata and metamorphism. By what means, then, were masses of strata many thousands of feet thick bent and contorted, and often raised high into the air, so as to produce existing scenic results by affording matter for rain and rivers to work upon? Not by igneous pressure from below raising the rocks, for that would stretch instead of crumpling strata, in the manner in which we find them in the Alps, Norway and the Highlands, or in less degree in Wales and Cumberland; but rather because of the gradual shrinkage of the earth's *crust*, which, here and there giving way, became crumpled along lines more or less irregular, producing partial upheavals. Thus while the absolute bulk of the globe was diminishing by cooling, the hardened crust, in its efforts to accommodate itself to the lesser bulk of the mass, became in places folded and fractured and dislocated again and again. This, according to the theory long ago proposed by Elie de Beaumont, and adopted by De la Beche in his 'Researches in Theoretical Geology,' is the origin of mountain chains.[1] After water took its place on the earth, by such processes of crust-movement land was again and again raised within the influence of atmospheric disintegration, and rain and glaciers, rivers and sea, acting on it, were enabled to sculpture its features and to distribute the materials of sedimentary strata. Such disturbances of strata have been going

[1] See also T. Mellard Reade, *The Origin of Mountain Ranges*, 1886; and the Rev. O. Fisher, *Physics of the Earth's Crust*, ed. 2 1889.

on through all known geological time, and doubtless are still in progress, though the main effects be produced deep below the surface.

Such shrinkage or crumpling, where it has been most intense, and on the greatest scale, is generally accompanied by gneissic or other metamorphic rocks, and by granite or its allies: rocks which have been subsequently brought to light by denudation.

Reasoning on these disturbances, we know that strata, which were originally deposited in an approximately horizontal form, have often descended thousands of feet towards the centre of the earth, by gradual sinking of the sea-bottom, and the simultaneous piling up of newer strata upon them. The layer that is formed to-day beneath the water forms the actual sea-bottom; but neither the land nor the sea-bottom is steady. The land is in places slowly descending beneath the sea, and sea-bottoms are themselves descending also. It has frequently happened, therefore, that for a long period a steady descent over a given area has taken place, and simultaneously with this many thousands of feet of strata have by degrees accumulated bed upon bed. It has, moreover, been suggested that the increase of sediment in one area, and the removal of material by denudation from another, have been sufficient to influence depression or upheaval of the unstable crust.

As we descend into the earth the temperature rises, whence, in the main, the theory of central heat has been derived. Below the influence of surface-changes, heat increases about 1° for every fifty or sixty feet; but the increase, which everywhere takes place, does so in a smaller ratio at greater depths. The temperature, however, at a depth of 30,000 feet, to which some strata must have sunk, might be estimated at about 500°.

Rocks of various kinds, some of which were once at the surface, have by means of great folds and other disturbances, been brought within the influence of internal heat as, for instance, in the bed marked *, Fig. 18, which may be supposed to represent a large tract of country. It must not be understood that the globe is entirely filled with melted matter—that is a question still in doubt; but it is by no means improbable that the heat in the interior of the globe may in places, and apparently capriciously, eat its way towards the surface by the hydrothermal fusion or alteration of parts of the earth's crust, in a manner not immediately connected with the more superficial phenomena of volcanic action. Under some such circumstances, we can easily understand how stratified rocks may have been so highly heated that they were actually softened; and most rocks being moist (because water that falls upon

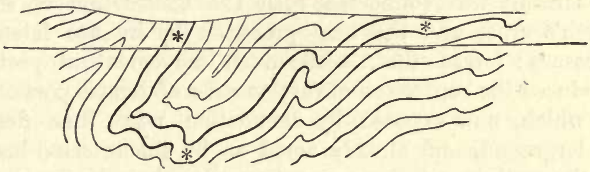


Fig. 18.—Section showing how Strata, by means of Contortion, may be brought within the Influence of the Earth's Internal Heat.

the surface often percolates to unknown depths), chemical actions were set going, resulting in a re-arrangement of the substances which composed the sedimentary rock. These results were no doubt accelerated by the crushing of the rocks that accompanied the crust-movements; but the observations of Mr. G. Barrow in the south-eastern highlands of Scotland have shown that the highly crystalline character of the schists is the result mainly of thermo-metamorphism, due to the intrusion of granitic rocks in connection with crust-movements, and that regional and contact metamorphism differ only in degree.

The tiny 'fluid cavities' that occur in the quartz of granites, and contain water which Dr. Sorby believes to have been a genuine constituent of the rock when melted, lead him to believe that the pressure under which granites were most probably formed, indicates depths from the surface varying from 15,100 to 65,500 feet. These conclusions lend support to the view that gneiss and granite were formed at depths that may be counted by many thousands of feet, and also give strength to the assertion, that under such circumstances water was present.

If the above views be correct, though many granites have been injected among strata, yet in the main, so far from the intrusion of granite having produced many mountains by mere upheaval, both gneiss and granite would rather seem to be often the results or accompaniments of the forces that formed certain mountain chains. Possibly this result was connected with the contraction of the earth's crust and the heat produced by intense lateral pressure: forces that, with much movement of parts, produced the contortion of vast masses of strata, portions of which, now exposed by denudation, were then deep underground, and already acted on by the internal heat of the earth in a degree proportionate to their depth.

CHAPTER V.

GENERAL ARRANGEMENT OF THE STRATIFIED FORMATIONS; HISTORY OF GEOLOGICAL OPINION; TABLE OF BRITISH FORMATIONS.

The geology of England and Wales is much more comprehensive than that of Scotland, in so far that it contains more formations, and its features therefore are more various. England is the very Paradise of geologists, for it may be said to be in itself an epitome of the geology of almost the whole of Europe, and much of Asia and America. Very few European geological formations are altogether wanting in England. On the Continent, however, some have a larger importance than in England, being more truly oceanic deposits in some cases, and more thoroughly developed lacustrine or terrestrial deposits in others. In some countries larger than England the whole surface is occupied by one or two formations, but in England nearly all the formations shown in the table (p. 47) are more or less developed. In Scotland, though a considerable variety of formations belonging to all the main divisions may be found, yet many of these occupy very limited areas, their succession is not so clearly displayed as in England, and we miss especially the Lower Cretaceous and great part of the Tertiary strata.

It took a long time, by analyses of the order of deposition of stratified rocks and their contents, for geologists to establish the facts and reasonings now generally accepted, and the chief advances have been made during the last hundred years, beginning with the work of Hutton and William Smith. Notices occur in the pages of Herodotus, Aristotle, Strabo, and Pliny, which scarcely amount to geological ideas, but which show that they were cognisant of the occurrence of shells far inland, and high on the mountains; and they also reasoned on the mutability of the relative levels and positions of sea and land.[1]

In old times fossil shells were usually referred to the Deluge; and this opinion for long prevailed among such men as Lister (1678), Burnet (1684), John Woodward (1695), and many more besides. Others, including Plot (1677), held the absurd opinion that fossils were 'sports of nature.' A few remarkable men held more correct views on the subject. In 1580, 'a potter,' says Fontenelle, 'who knew neither Latin nor Greek, was the first who dared assert in Paris, and to the face of all the doctors, that fossil shells were true shells, deposited formerly in the sea in the places where they are found.' This man was Bernard Palissy. In 1669, Steno published his remarkable treatise *De Solido intra Solidum naturaliter contento*, in which he demonstrated that the fossils found in rocks are truly organic; and that they were buried in marine sediments, in the same manner that the remains of plants and marine animals are now entombed in modern sea-bottoms. Hooke, in his 'Discourse of Earthquakes' (1688), maintains like opinions; and he inferred the extinction of species, and the introduction of varieties, consequent on changes in physical geography. Still further, he speaks of the 'records of antiquity which nature has left as monuments . . . and though it is very difficult to read them, and to raise a *chronology* out of them, . . . yet 'tis not impossible.' This is the earliest distinct hint of the principle of *succession of life in time*.

[1] See Ramsay, *Passages in the History of Geology*, 1848–49; also Fitton, *Notes on the Progress of Geology in England* (reprinted from the *Phil. Mag.*), 1833; and Lyell, *Principles of Geology*, ed. 12, vol. i., 1875.

In 1760, Michell, in his famous Memoir on Earthquakes, in the 'Philosophical Transactions,' shows a clear perception of an order of superposition in strata, but he does not combine it with the fact of a parallel succession of life. About this time matters begin to become more definite, and a physician of Rudelstadt, George Christian Fuchsel, showed a remarkable knowledge both of *the succession of stratified formations and of the succession of life in time*, and his writings contain even more than the germ of many of the truths that, during the present century, have given so rapid an impulse to the science. In his system he distinguishes, resting on primitive schists, and ranging up to what we now call the Trias, thirteen subformations, each being characterised by a distinctive assemblage of fossils, or peculiarities of marine and fluviatile deposition; and he taught that the physical phenomena of the earth are constant and unchangeable.[1]

Rather later, Werner, by his enthusiasm, eloquence, and skill as a mineralogist, also lent much aid to the cause; but his determined adherence to the dogma that all rocks are aqueous, did more to retard the advance of truth. His far greater opponent, Hutton, (1788), in his 'Theory of the Earth,' expounded the true doctrine, which may be summed up as follows:—

1st. That, in the known geological history of the world, the course of events has never been disturbed by universal paroxysmal catastrophes, but that the course of change has been similar to that of the existing economy of nature.

2nd. That we know of no set of igneous rocks that can be proved to be of generally older origin than the earliest stratified deposits, but that they may often be proved to be of posterior origin.

3rd. That the stratified masses were formed from the waste of pre-existing rocks, mingled with organic exuviæ.

4th. That such strata afford a measure of the amount of pre-existing land destroyed to afford materials for their formation.

5th. That there may be a progressive formation of rocks

[1] *Journal de Géologie*, vol. ii., 1830, p. 191.

in the bottom of the sea, contemporaneous with great and repeated alterations of lower strata, that approach the regions of internal heat (metamorphism).

6th. That all strata being derivative, and a machinery existing capable alike of erecting and destroying rocks, in the whole course of *visible* nature 'we find no vestige of a beginning—no trace of an end.'

In these modern days very few persons read Hutton, and those who trouble themselves about old geology are in general more familiar with Playfair's delightful 'Illustrations of the Huttonian Theory' than with Hutton's great original work, in which the philosophy of igneous, stratigraphical, and metamorphic geology was described in a manner that excited the admiring wonder of a few who in those days were able to appreciate his generalisations.

To the less precise generalisations of earlier observers, William Smith added the complete proof of the succession of life in time, demonstrating, as he did in England, a clear sequence of strata, each formation being characterised by its own suite of fossils. To effect his object, Smith traced the English formations from end to end of the country with unwearied devotion, and at length, in 1815, produced his great geological map of England. He struggled long, almost unrecognised in his labours, but when they were wellnigh at an end, men began by degrees to realise that a master was among them. In 1831, the first Wollaston medal was awarded to him by the council of the Geological Society, while in his annual address Sedgwick hailed William Smith as 'the Father of English Geology.'

The doctrines of Hutton and Smith gave the key to great part of the modern system of geology, and later works have so amplified and illustrated their conclusions, that geology now fairly holds its place as a science. Among the 'Old Masters' we enrol Macculloch, Buckland, Conybeare, Sedgwick, De la Beche, Murchison, Fitton, Lyell, John Phillips, and Lonsdale; neither should we forget John Farey, who did much in early days to establish the truth of the observations of Smith, nor the labours of those pioneers among the fossils, Parkinson, the two Sowerbys, and Mantell. Few persons now study the old prophets and fathers in geology, and therefore I have thought it well to give the foregoing imperfect sketch of the slow progress by which men have become able to determine the order of deposition of formations, and of their fossilised contents.

In the succeeding chapters a general account of each formation and of its leading fossils will be given; and it should be borne in mind that each formation is but the local expression of certain physical conditions. The words formation, epoch, series, period, are in this book only used as convenient terms. When analysed, they often imply that certain links, chapters or whole books are locally missing in geological history, epochs in fact unrepresented in given areas by stratified formations.[1]

TABLE OF BRITISH FORMATIONS.

Cænozoic	Quaternary	RECENT	Alluvium, peat, some cavern-deposits, estuarine beds, and beach-deposits: of Neolithic and later ages	
		PLEISTOCENE	River and estuarine beds, and some cavern-deposits, with Palæolithic implements, bones of Mammoth, &c. Clyde Beds, Raised beaches, Moraines and Eskers or Kames, Boulder-clays, Gravels, Sands, and Loams	
	Tertiary	PLIOCENE	Cromer Forest Bed Series	Estuarine and freshwater
			Norwich Crag	Marine
			Red Crag	
			Coralline Crag and Lenham Beds	
		OLIGOCENE	Hamstead Beds	Fluvio-marine Series
			Bembridge Beds	
			Osborne Beds	
			Headon Beds	
		EOCENE	Bagshot Beds; including Barton, Bracklesham, and Bovey Beds	Marine and (locally) freshwater
			London Clay	Marine
			Oldhaven and Blackheath Beds	
			Woolwich and Reading Beds	Freshwater, estuarine, and marine
			Thanet Beds	Marine

[1] See Ramsay, 'On the Breaks in Succession of the British Strata,' *Addresses to Geol. Soc.*, 1863–64.

TABLE OF BRITISH FORMATIONS—*continued.*

Secondary or Mesozoic	CRETACEOUS	Chalk Upper Greensand Gault Lower Greensand	Marine
	WEALDEN-PURBECK	Weald Clay Hastings Beds Purbeck Beds	Freshwater and estuarine
Jurassic	OOLITIC SERIES	Portland Beds Kimeridge Clay Corallian Beds Oxford Clay and Kellaways Beds Cornbrash	Marine
		Forest Marble, Bradford Clay, and Great Oolite Clay Great Oolite and Stonesfield Slate Inferior Oolite Series, including Midford Sand (passage-beds)	Marine in middle and south of England; estuarine (in part) in middle of England, Yorkshire, and Scotland
	LIASSIC	Upper Lias Middle Lias Lower Lias	Marine
	TRIASSIC	Rhætic Beds New Red Marl (Keuper) New Red Sandstone (Bunter)	Inland sea or Lake-deposits, for the most part salt
Palæozoic	PERMIAN	Magnesian Limestone Series (Zechstein) Lower Permian (Rothliegende)	
	CARBONIFEROUS	Coal-measures Millstone Grit	Terrestrial, freshwater, and marine
		Carboniferous Limestone Series and Calciferous Sandstone	Marine and estuarine, &c.
	OLD RED SANDSTONE AND DEVONIAN	Upper Old Red Sandstone Devonian Lower Old Red Sandstone	Old Red Sandstone, freshwater lakes; Devonian, marine
	UPPER SILURIAN	Ludlow Series Wenlock Series May Hill or Llandovery Series	Marine
	LOWER SILURIAN (Ordovician)	Bala and Caradoc Series Llandeilo Beds Arenig Series	
	CAMBRIAN	Tremadoc Series Lingula Flag Series Menevian Series Harlech and St. David's Series	
Pre-Cambrian and Archæan	TORRIDONIAN	Torridon Sandstone	
	DALRADIAN	Highland Schists	
	LEWISIAN	Hebridean or Fundamental Gneiss	

CHAPTER VI.

ARCHÆAN AND CAMBRIAN ROCKS.

UNDER the term ARCHÆAN we include the oldest rocks at present known in the world. They are metamorphic and volcanic in character; they include granitoid rocks and various schists; and together form a complex group that may include rocks of distinct ages, all highly altered and crumpled. Their relative age is known chiefly by the occurrence of fragments, derived from them, in the overlying Cambrian conglomerates: hence they are often termed Pre-Cambrian. Their presence in the Malvern Hills, in Anglesey,[1] in the region of the Longmynd and the Wrekin, is generally admitted. They probably occur in other tracts. In Caernarvonshire, at St. David's in South Wales, at the Lizard Point in Cornwall, and elsewhere, Pre-Cambrian rocks have been described, but their age has been questioned by some geologists. Thus the granitoid rock of St. David's, termed Dimetian by Dr. Hicks, has been considered by Sir A. Geikie to be intrusive; while the Pebidian Series, which Dr. Hicks regarded also as Pre-Cambrian, though newer than the Dimetian, has been placed, as a volcanic group, at the base of the Cambrian system by Sir A. Geikie. On the other hand,

[1] Though Sir Andrew Ramsay had questioned the existence of Pre-Cambrian rocks in Anglesey, yet (as Sir Archibald Geikie has remarked) 'were he able once more to ramble over those hills and shores which he knew and loved so well, he would himself, in the light of present knowledge, freely admit' their great antiquity.

the Pebidian has been compared with the Wrekin volcanic series (Uriconian) and with the Caldecote volcanic series of Nuneaton and Hartshill, both of which underlie the Cambrian quartzites, as shown by Dr. Callaway, Professor Lapworth, and others. The presence of Pre-Cambrian rocks in the region of Charnwood Forest has also been maintained by Professor Bonney and the Rev. E. Hill; though they admit that clear evidence of such great antiquity has yet to be brought forward.

In the Outer Hebrides and on the west coast of the Highlands from Cape Wrath to Loch Maree, Gairloch, and Loch Torridon, rocks occur of highly metamorphic gneiss, interpenetrated by numerous veins of granite, and of the coarsely crystalline variety known as pegmatite or 'giant granite.' These rocks, grouped as Lewisian or Hebridean Gneiss (the 'Fundamental Gneiss' of Murchison), are overlaid in the west of Sutherland and Ross-shire by thick masses of reddish-brown sandstone, known as the Torridon Sandstone; and between the two groups there is a marked unconformity. No fossils, save possible traces of Annelids, have been found in this ancient sandstone, and being overlaid discordantly by Lower Cambrian rocks, its age is clearly Pre-Cambrian. Despite its antiquity much of the Torridon Sandstone appears no more altered than the Old Red Sandstone, which it much resembles.

Over large tracts in the central Highlands, and extending northwards to Sutherlandshire, are the schists which at one time were regarded as altered Lower Silurian rocks.[1] Their age is now regarded as most uncertain—they may indeed include various formations. They comprise garnetiferous and other schists, such as graphite-schist, and they include bands of quartzite. For this great Grampian

[1] For accounts of the structure of the N.-W. Highlands, see Lapworth, *Geol. Mag.*, 1883, pp. 120, &c., 1885, p. 97; and 'Report of Recent Work of Geological Survey,' *Quart. Journ. Geol. Soc.*, vol. xliv. p. 378. References are there given to the work of Murchison, Nicol, and others.

Series, as Dr. Hicks has termed it, Sir A. Geikie employs the name Dalradian, as a convenient epithet until the true stratigraphical position of the rocks is definitely ascertained. Bands of altered limestone also occur in this group at Loch Tay and near Kirkmichael, while the graphite schists and quartzites form great part of Islay, and the quartzites rise up in the Paps of Jura.

The CAMBRIAN and SILURIAN ROCKS of the British Series come next in succession. If these strata were to be classified for the first time in England, I would divide them into three, as the most convenient method. The first series (= CAMBRIAN) would include the purple and green grits and slates of Harlech and Llanberis, and range upward as high as the top of the Tremadoc Slates; the second (= LOWER SILURIAN or ORDOVICIAN) would range from the base of the Arenig Slates to the top of the Bala or Caradoc Beds, and the third (= UPPER SILURIAN) from the base of the Llandovery Beds to the top of the Ludlow group. In Wales and its neighbourhood, where the most typical series is found, each of these great boundary-lines is marked by unconformity, and analogous unconformities are found elsewhere in the British Islands.

Since the first publication, by Murchison, of 'The Silurian System,' dedicated to Sedgwick in 1839, there has been but little unanimity among British geologists on the subject. In 1841–42 De la Beche and those who worked with him on the Geological Survey, adopted the term Cambrian for all the purple grits and slates of St. David's and the Longmynd, then supposed to be unfossiliferous; while the name Silurian, nearly in the same sense as used by Murchison, was employed for all the strata between the uppermost beds of these rocks and the top of the Ludlow Series. When the survey reached North Wales this classification continued for a time unchallenged. Sedgwick had previously called the equivalents of part of these strata in the north of England the CUMBRIAN Series; and at that time he termed the blue and grey slaty series of Wales the

CAMBRIAN Series, on the assumption, then unquestioned, that they were all older than the recognised Llandeilo Flags of Murchison. But in the progress of investigation by Sedgwick and others, it appeared that his original Cambrian, and Murchison's original Lower Silurian strata, were in large part equivalent; and the great Professor of Cambridge naturally reclaimed all that part of his kingdom, the boundaries of which had, for all Wales, not been clearly defined when he first tried to subdue it. He, therefore, maintained that the true Cambrian Series included all the strata from the base of the purple slates and grits to the top of the Bala Beds or Caradoc Sandstone of Murchison.

By way of healing differences and striking a just middle boundary, John Phillips and Lyell proposed that the term Cambrian should be used to include all the strata from its known base in Shropshire, at St. David's, and in North Wales, through the Lingula Flags up to the top of the Tremadoc Slates, a proposition which satisfied neither of the claimants.[1] It is now generally adopted.

This is not a book in which to enter into the details of a controversy which has comparatively little interest beyond the confines of the British Islands; but it is needful to sketch out the questions involved, that students may know something of the origin of the varieties of opinion implied in the different nomenclatures.[2]

THE CAMBRIAN ROCKS consist in their lower portion of the Harlech and St. David's Series. In Wales these beds comprise the purple grits and slates, that form the greater part of the group of hills that lie north-east of Cardigan

[1] In 1879 Professor Lapworth, in order to meet the views of rival schools, introduced the name ORDOVICIAN for the Cambro-Silurian or Lower Silurian system (*Geol. Mag.*, 1879, p. 13).

[2] See Murchison, *Siluria*, ed. 5, 1872; Sedgwick, preface to Salter's *Catalogue of Cambrian and Silurian Fossils*, 1873; J. E. Marr, *Classification of the Cambrian and Silurian Rocks*, 1883; and also the *Life of Murchison*, by A. Geikie, 2 vols., 1875; and the *Life and Letters of Sedgwick*, by J. W. Clark and T. McK. Hughes, 2 vols., 1890.

Bay between the estuary of the Mawddach and the country south-west of Ffestiniog. In that region their stratigraphical relation to the overlying rocks will be seen by referring to Fig. 114. They there constitute the lowest central strata of a broad anticlinal curve. They are also well seen in the passes of Llanberis and Nant Ffrancon in Caernarvonshire, where the celebrated slate quarries of Penrhyn and Llanberis lie in these strata. The slates are purple, purplish-blue, and green; and associated with them are beds of grey grit and conglomerate. In the upper green slates of the Penrhyn quarries the Trilobite *Conocoryphe viola* (described by Dr. Henry Woodward) is the first fossil ever found in these rocks. It is important to observe that at Llanberis the conglomerates

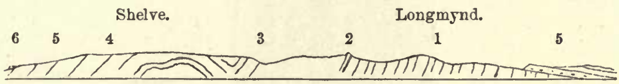


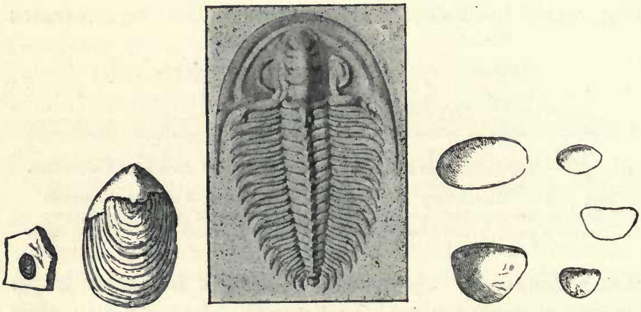
FIG. 19.—SECTION ACROSS THE LONGMYND AND SHELVE COUNTRY.

6. May Hill or Llandovery Beds. 5. Bala or Caradoc Beds. 4. Llandeilo Beds. 3. Arenig Beds, resting on the quartzite of the Stiper Stones. 2. Tremadoc Beds. 1. Longmynd series (now regarded as of Pre-Cambrian age).

contain numerous water-worn pebbles of felspathic traps, jasper, greenstone, black and purple slate, &c., so that these have been derived from pre-existing rocky lands, of which traces are now recognised in certain areas of Pre-Cambrian rocks in Anglesey and elsewhere.

Cambrian strata also occur in the neighbourhood of Church Stretton and other parts of Shropshire, where the strata stand nearly on end. The lowest beds consist of quartzite, comparable with that of Hartshill, near Nuneaton, in Warwickshire, and this overlies the Uriconian (Pre-Cambrian rocks of the district). Above is the Comley Sandstone, in which Professor Lapworth has discovered the Trilobite *Olenellus*, also *Kutorgina*, &c. Here, indeed, *Olenellus*, which characterises the Lower Cambrian fauna, was for the first time found in Britain (see Fig. 20). The only traces of fossils previously discovered were worm-burrows, and the Trilobite *Palæopyge Ramsayi.*

At St. David's, in Pembrokeshire, in equivalent strata, Dr. Hicks found the following fossils in purple shales among the lowest beds of the series (Caerfai group):—A small bivalve Crustacean *Leperditia cambrensis*, traces of *Olenellus*, and small Brachiopods, such as *Lingulella ferruginea* and *L. primæva* (Fig. 20). In a higher part of the series (Solva group), consisting chiefly of yellowish sandstones and grey shales, now grouped with the Middle Cambrian, he also found Sponges (*Protospongia*), various



Lingulella ferruginea. Olenellus callavei. Leperditia cambrensis.

Fig. 20.—Group of Lower Cambrian Fossils.

Trilobites, *Microdiscus sculptus*, *Paradoxides Harknessi*, *P. aurora*, *Plutonia*, *Conocoryphe*, *Agnostus cambrensis*, and a Pteropod *Theca antiqua* (Fig. 21). These rocks had previously been considered unfossiliferous, and the discovery is important as showing that in sediments so old there existed a considerable development of life of the same general type as that found in overlying strata. That such diverse organisms existed in early Cambrian times, leads to the belief that the beginnings of life must be looked for in far more ancient strata.

In Sutherlandshire strata of Cambrian age lie uncon-

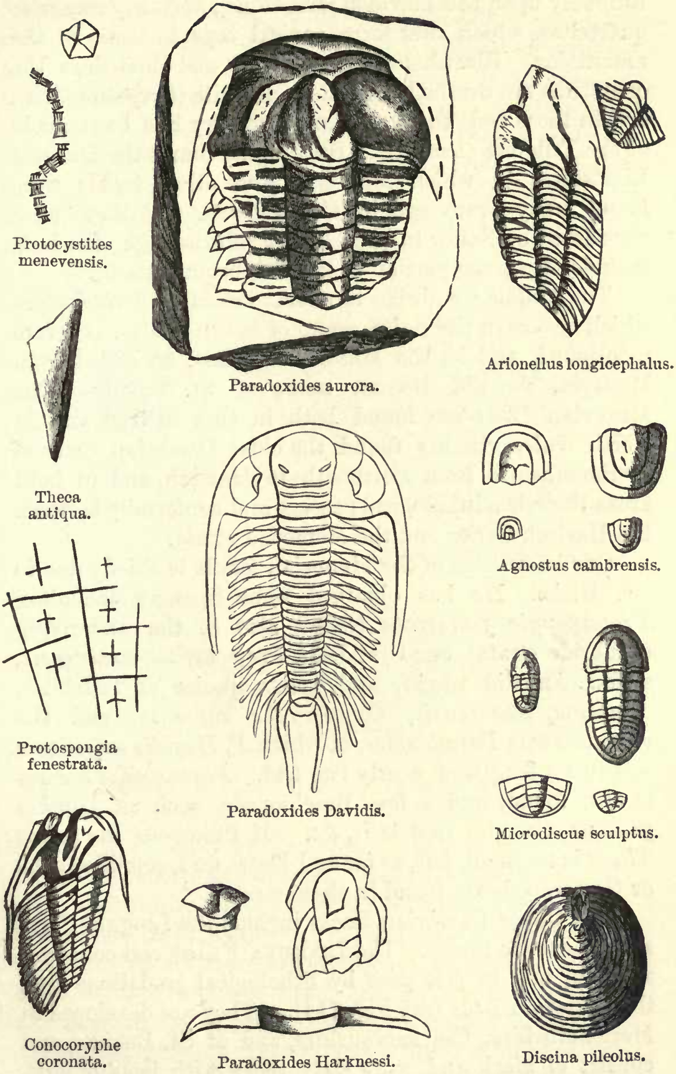


FIG. 21.—GROUP OF MIDDLE CAMBRIAN (MENEVIAN) FOSSILS

formably upon the Torridon Sandstone; and they comprise quartzites, which now form conical tops to some of the mountains. Elsewhere in Sutherland and Ross-shire the quartzites are overlaid by shales and grits (Serpulite Grit), and in these beds the important discovery has been made of the Trilobite *Olenellus*. Still higher comes the Durness Limestone, in which *Maclurea* and other fossils were found many years ago by C. W. Peach, and these were considered by Salter to be of Lower Silurian age; the beds include also some portion of the Cambrian system.

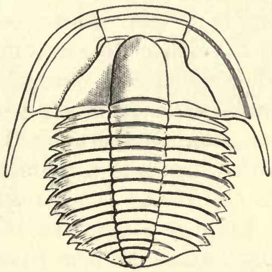
The Middle Cambrian is characterised by *Paradoxides* which occurs in the Solva group of South Wales, as before mentioned, and in the MENEVIAN BEDS, so called from Menapia, the old Roman name of St. David's. The Menevian Beds are found both in that district and in North Wales, circling round the older Cambrian rocks of Merionethshire from Barmouth to Harlech, and in both areas there is a lithological passage and conformity between the Harlech Series and the Menevian strata.

Our knowledge of the Menevian fossils is chiefly due to Dr. Hicks. He has obtained some Sponges, including *Protospongia fenestrata* (found also in the underlying Cambrian strata), one Cystidean, *Protocystites menevensis*, a few Annelid tracks, and many species of Trilobites, *Agnostus cambrensis*, *Conocoryphe coronata*, and the characteristic *Paradoxides*, of which *P. Davidis* sometimes attained a length of nearly two feet. *Paradoxides aurora* is also found, and a few Brachiopods, such as *Discina pileolus*, *Obolella sagittalis*, &c. Of Pteropods the genus *Theca* is common, but, as far as I know, no Lamellibranchs or Gasteropods are found in these strata.

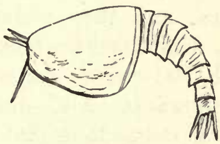
The Upper Cambrian Rocks include the Lingula Flags and Tremadoc Slates. The LINGULA FLAGS rest conformably on, and in fact pass by lithological gradations into, the Menevian Beds (see Fig. 114). They are developed in Merionethshire, Caernarvonshire, and at St. David's, and consist of black and grey slaty rocks with beds of grit.

In these a marked and distinctive suite of fossils occurs, the chief of which are *Lingulella Davisi*, many Trilobites, such as *Conocoryphe bucephala*, and *Agnostus pisiformis*, and several species of the characteristic *Olenus*, also a phyllopod Crustacean, *Hymenocaris vermicauda*. Various Annelids are found, such as *Cruziana semiplicata*, and in the higher part of the strata Polyzoa, of the genus *Fenestella*, and the Hydrozoan *Dictyonema sociale*. The Brachiopods

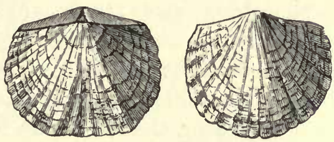
Lingulella Davisi.



Conocoryphe bucephala.



Hymenocaris vermicauda.



Orthis lenticularis.

FIG. 22.—GROUP OF UPPER CAMBRIAN (LINGULA FLAG) FOSSILS.

include, in addition to *Lingulella*, *Kutorgina cingulata*, *Orthis lenticularis* and others. *Theca* also occurs.

In Shropshire the Shineton Shales comprise beds characterised in their lower portion by *Dictyonema sociale*; and higher up by *Asaphus Homfrayi*, a Trilobite characteristic of the Tremadoc Beds. So far, from the Harlech Beds, through the Menevian Beds, and Lingula Flags, there is no marked plane of division, but a lithological gradation from the lower to the higher strata, accompanied by the passage of species from lower to higher geological horizons. Here as elsewhere the palæontological 'zones' do not conform to the main lithological divisions of the formations; thus, as before noted, the Solva group of Dr. Hicks, which is the upper part of the St. David's Series, belongs palæontologically to the *Paradoxides* zone, which is linked with the Menevian.

The TREMADOC SLATES succeed the Lingula Flags, and may be considered as an upper member of that series. There is no clear lithological boundary-line between them, and the whole lie conformably. Trilobites are known in Wales, and also in Shropshire, from these strata, the most characteristic of which are *Asaphus Homfrayi*, *Angelina Sedgwicki*, *Conocoryphe depressa*, and *Niobe Homfrayi*. *Orthis Carausi* is a characteristic Brachiopod, and *Lingulella Davisi* and *L. lepis* are common to these strata and to the Lingula Flags. In Ramsey Island, near St. David's, many Lamellibranchs have been found by Dr. Hicks, of the genera *Palæarca*, *Modiolopsis*, and others, also *Theca operculata* and other Pteropods, *Bellerophon arfonensis*, &c. Cephalopods make their appearance, and they include *Orthoceras sericeum*, and *Cyrtoceras*. Encrinites are found, and the oldest known British Starfish, *Palasterina ramseyensis*. Graptolites also make their appearance. Altogether, as now known, the life of the time was richer than that of the older Cambrian strata, but all these faunas are probably very imperfect and fragmentary in the British area.

Leaving these details of stratification, I will now endeavour to catch a glimpse of the physical geography of our area during the time when the Cambrian rocks were being deposited.[1] The thick strata of sandstones in the Lower Cambrian rocks of Merionethshire indicate the neighbourhood of land, and in Caernarvonshire the numerous beds of sandstone and conglomerate interstratified with mud deposits—now slates—point not only to the

[1] See also Ramsay, 'Geology of North Wales' (*Mem. Geol. Survey*, vol. iii.), ed. 2, 1881.

proximity of land, but even give a clear idea of the kinds of rock of which that land was made. In the 8,000 feet of these rocks in Merionethshire there is very little slate, and even the 700 or 1,000 feet of interstratified slaty beds in Caernarvonshire are quite subordinate to the grits and con-

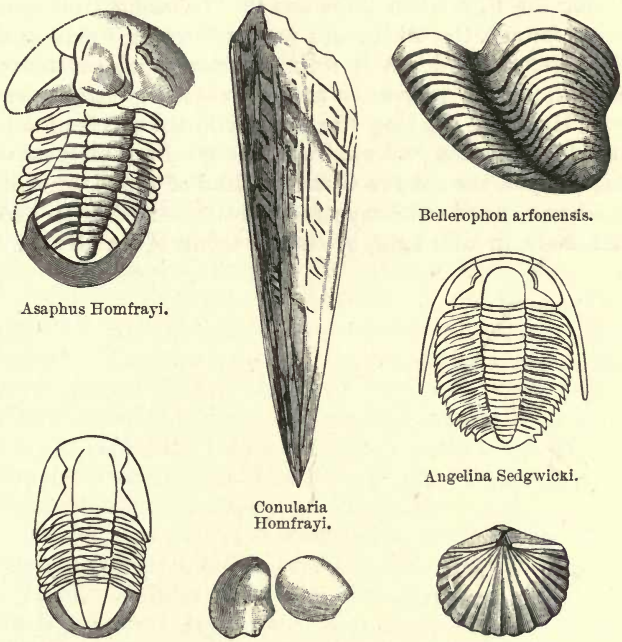


Fig. 23.—Group of Upper Cambrian (Tremadoc) Fossils.

glomerates. The structure of this land may be partly inferred from the nature of the pebbles in the coarse conglomerate, which are water-worn (see p. 53), and fragments of this old continent probably still exist in the Pre-Cambrian areas before mentioned.

While the Menevian and Lingula Beds were being deposited I think it more than probable that the Pre-Cambrian continent still yielded up its materials, for in the gritty strata that form a large part of the Lingula Flags, and in the frequent presence of current-marks (often called ripple-marks), there are many signs that these strata were deposited in shallow water. Thus it would happen, that during the time when these and the Tremadoc Beds were being formed, the whole area was undergoing a process of slow sinking, and into it sediments were being constantly carried, just in proportion as the gradual depression went on. Hence, in the long run, what with the effects of sub-aërial degradation, and what with the results of progressive submersion, the old Pre-Cambrian land of this neighbourhood was buried and disappeared, until revealed again here and there, in later ages, by similar agents of denudation.

CHAPTER VII.

LOWER SILURIAN [ORDOVICIAN] ROCKS; ARENIG, LLANDEILO, BALA, AND CARADOC BEDS.

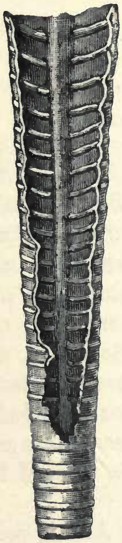
The Arenig Beds succeed the Tremadoc Slates at St. David's in South Wales, and in North Wales they also overlie the Tremadoc Slates between Towyn and the neighbourhoods of Dolgelly, Ffestiniog, Tremadoc, and Criccieth in Caernarvonshire, north of which they also occur in part of the country between Caernarvon and Bangor. They were first distinguished by Sedgwick, and named Arenig Slates. Afterwards they were termed Lower Llandeilo Beds by Murchison, who had previously included them as part of the Llandeilo Flags, in his descriptions and sections of the Lower Silurian rocks that lie west of the Stiper Stones, near Shelve, in Shropshire.

In the large district of Merionethshire the Arenig rocks appear at the base of the great volcanic series of which the mountains of Cader Idris, Aran Mowddwy, Arenig, and the Moelwyns form prominent features in the landscape. They are in these districts never more than about 800 feet in thickness, and the Arenig Beds of Merionethshire at their base invariably consist of beds of grit, sometimes conglomeratic. The higher strata of this sub-formation are generally slaty, and have been grouped as the Llanvirn Series by Dr. Hicks, from Llanvirn, near St. David's. For reasons that will afterwards appear, I believe that the Arenig strata, on a large scale, rest unconformably on the underlying rocks of North Wales.

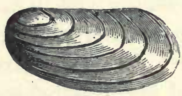
In Cumberland the Skiddaw Slates form the mountains of Skiddaw and Saddleback; and from the borders of the Old Red Sandstone, or Carboniferous basement-bed, a few miles further east, they stretch right across the country westward to Egremont and northward to near Cockermouth, where they are directly overlaid by the Carboniferous Limestone.

According to the observations of Mr. J. E. Marr the Skiddaw Slate series includes diverse deposits: the uppermost beds represent part of the Tremadoc Beds and the whole of the Arenig Series; but little is known of the lower portion, which has not yet yielded fossils. The rocks are much folded and contorted.

Beds grouped with the Skiddaw Slates occur over a large area in the Isle of Man; but these have not proved fossiliferous. In the Shelve area the Arenig rocks consist in upward sequence of beds, largely composed of grits and shales, with volcanic ashes and lavas in the upper part, the whole resting on the quartzite of the Stiper Stones.



Orthoceras mendax.



Palæarca amygdalus.

Fig. 24.—Arenig Fossils.

In Scotland the beds are represented to some extent in the Ballantrae Series of Ayrshire and Lanarkshire, though Professor Lapworth has described the group as a complex of stratified, altered, and igneous rocks, the relations of which have yet to be worked out. He has obtained, however, definite evidence of Arenig Graptolites in black shales at Bennane Head. The Durness strata may belong in part to the same rocks.

In Britain the fossils that belong to this part of the Lower Silurian series are not very numerous, taken as a whole, though some groups are very conspicuous. Thus, Graptolites are remarkably abundant, including *Didymograptus*, *Tetragraptus*, and *Phyllograptus*. These organisms, though of a lowly type, have been found exceedingly valuable in marking horizons or 'zones' in the Arenig and succeeding Silurian strata.

Trilobites occur in the same rocks, including *Agnostus hirundo*, *Æglina*, *Asaphus Homfrayi*, *Illænus*, *Ogygia Selwyni*, *Trinucleus Ramsayi*, *Calymene parvifrons*, and many others. Of Brachiopods there are *Lingulella lepis*, *Orthis lenticularis*, *Obolella*, and others. Of Lamellibranchs there are *Modiolopsis*, *Palæarca socialis*, *P. amygdalus*, *Ctenodonta*, and *Redonia anglica*. Pteropods of the genera *Theca* and *Conularia* are found. *Bellerophon* and *Orthoceras mendax* are likewise met with. Among the Gasteropods *Pleurotomaria llanvirnensis* is noteworthy.

Though in Wales the base of the Arenig Beds is clear, it seems as yet impossible to draw any definite physical boundary between the Arenig Beds and the overlying Llandeilo Slates, for there is nothing like unconformity, and no marked lithological difference in passing from one to the other. Nevertheless, there is a very limited passage of species from the Arenig Beds into those of the so-called Llandeilo Series.

Just about this time an important episode took place in the history of the Llandeilo and Bala Beds over large tracts of Wales and Cumberland, for a series of volcanic eruptions occurred on a great scale while the strata were being deposited (Fig. 114).

In North Wales the LLANDEILO and BALA or CARADOC BEDS combined attain a thickness of from 4,000 to 6,000 feet, consisting chiefly of slaty rocks, sometimes interstratified with grits and occasional bands of limestone, of which the *Bala Limestone* is the most conspicuous. Thus, the Llandeilo Flags of North Wales are very unlike those of Llandeilo, which are generally called Upper Llandeilo

Beds. The whole series ranges right round the mountains of Cader Idris, Aran Mowddwy, Arenig, and the Moelwyns, resting on the lava beds and ashes, and overlaid on the east by Upper Silurian strata (see Fig. 109). They also form, with igneous rocks, the larger part of the Berwyn mountains, and with the Arenig Slates the whole of the ground between the Stiper Stones and the Upper Silurian rocks of Chirbury and Montgomery (Fig. 19, p. 53). The typical Caradoc Sandstone, crossing the strike, ranges between Church Stretton and Caer Caradoc, from whence it stretches in a broad band northward towards the Wrekin and southward to Corston. Thus, above the Arenig Beds in Shropshire we have a succession of Llandeilo Beds (in ascending order) of shales with *Didymograptus Murchisoni*, limestone with *Ogygia Buchi*, and black flags with *Cœnograptus*; while higher up we find a series of grits, mudstones, volcanic ashes, and shales, on the west —represented by the Hoar Edge Grits, Harnage Shales, Chatwall or Horderley Sandstone, and Cheney Longville Flags on the east. These are overlaid by the Onny Shales with *Trinucleus*.[1]

The greater part of South Wales is formed of slates and grits of Llandeilo and Caradoc age, lying west and north of the Upper Silurian and Old Red Sandstone strata; and the same formations, associated with volcanic rocks, rise like an island surrounded by Upper Silurian strata in the country between Builth and Llandegley in Radnorshire.

In South Wales, where they were first described by Murchison, the Llandeilo Beds consist of sandy, calcareous flags, black slaty rocks, grit, and sandstone. A few beds of limestone occur in them in Caermarthenshire, at Llandeilo, and in Pembrokeshire, near Narberth; and the Bala Limestone is found higher in the series in the Caradoc or Bala Beds of Merionethshire. They are often highly

[1] Lapworth, 'Preliminary Note on the Ordovician Rocks of Shropshire,' *Geol. Mag.*, 1887, p. 78.

fossiliferous. There is a much larger development of fossils in the Llandeilo Flags than in the pre-existing Silurian strata. Among the Gasteropods, *Murchisonia*

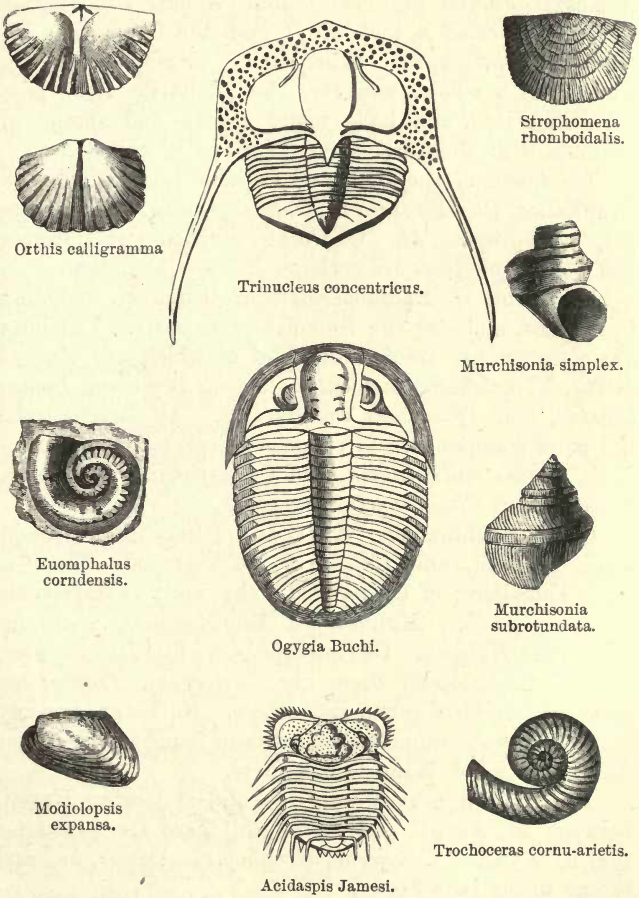


FIG. 25.—GROUP OF LLANDEILO FLAG AND CARADOC OR BALA FOSSILS.

simplex and *Euomphalus corndensis* are found, though rarely. Among the Trilobites of the Llandeilo Beds *Barrandea* and *Ogygia* are common, *Ogygia Buchi* being especially characteristic; *Asaphus tyrannus*, *Ampyx nudus*, and *Acidaspis Jamesi* are also found. Among Brachiopods *Orthis vespertilio* is met with; and the Graptolites include *Didymograptus Murchisoni*, *Diplograptus*, &c. Viewed as a whole, however, the Llandeilo Beds pass insensibly into, and have many genera and species in common with, the Caradoc Sandstone or Bala Beds.

The fossils of the Bala and Caradoc Beds include the Graptolites, *Climacograptus*, *Didymograptus*, *Dicellograptus*, *Diplograptus*, &c. Of Corals, *Heliolites interstincta* and *Syringophyllum* are perhaps the most abundant.

Fragments of Echinodermata are common, including Cystideans, and also the Star-fish, *Palæaster*. Trilobites are conspicuous, among the chief of which are *Ampyx nudus*, *Homalonotus bisulcatus*, *Illænus Bowmani*, *Lichas laxatus*, and *Trinucleus concentricus*. Of Brachiopods, the most common are *Strophomena depressa*, *S. rhomboidalis*, *Orthis calligramma*, and *O. vespertilio*. *Leptæna*, *Lingula*, and *Rhynchonella* also occur.

Of Lamellibranchs there are *Ctenodonta*, *Modiolopsis expansa*, and *Palæarca*. Of Pteropods *Theca* is most abundant; of Gasteropods, the most characteristic are *Euomphalus*, *Murchisonia subrotundata*, *Pleurotomaria*, and *Holopea*. Of Heteropods, we find *Bellerophon*; and of Cephalopods there are *Cyrtoceras*, *Trochoceras cornu-arietis*, *Orthoceras*, and others. No Fishes nor any other vertebrate animals have yet been found in the Lower Silurian rocks of Wales or elsewhere.

In Cornwall, near Mevagissey, and at Gorran Haven, between St. Austell and Falmouth, there are quartzites that have yielded *Calymene*, *Strophomena*, *Orthis*, &c., and belong to the Bala Series.

In Cumberland the Coniston Limestone is believed to be the equivalent of the Bala Limestone of North Wales, and the assemblage of fossils in each is very nearly the same.

In the south of Scotland Lower Silurian rocks extend across the country in a widening belt from near Dunbar to Port Patrick, forming portions of the southern uplands, the Lammermuir, Moorfoot, Lowther, and Carrick Hills (see Fig. 108). There they consist chiefly of grits and slaty beds, much contorted and faulted, and where bosses of granite occur in the western part of the area, the rocks are often much metamorphosed.

In the Moffat region to the north-east, and in that of Girvan and Ballantrae to the south-west, the succession of the strata and their fossils has been worked out in great detail by Professor Lapworth. The beds comprise the Glenkiln and Hartfell Shales of Moffat, and various divisions from the Ardwell Beds to the Ardmillan Series in Ayrshire. They represent the Llandeilo and Bala Series, and contain numerous Graptolites, species of which are found to characterise different stages in the rocks.[1] Dr. G. J. Hinde has described a Radiolarian chert which occurs below the Glenkiln Shales.

The Radiolaria are tiny organisms that belong to the lowest division of animal life (Protozoa). Many of them, of which the existing Polycistina is a leading form, have siliceous skeletons, which often exhibit a lattice-like structure. Hence owing to the accumulation of vast quantities of these microscopic structures, bands of chert (a hard and compact siliceous rock) have been formed. Lately Mr. Howard Fox and Mr. J. J. H. Teall have discovered radiolarian chert, associated with shales and limestones, in Mullion Island, off the western coast of the Lizard in Cornwall. As many as thirty bands of chert were noticed in a thickness of three feet. The age of these bands has yet to be determined, though they may be of Lower Silurian (Ordovician) age. Curiously enough, they occur

[1] *Quart. Journ. Geol. Soc.*, vol. xxxiv. p. 240, and vol. xxxviii. p. 537; *Geol. Mag.*, 1889, pp. 20, 59.

interbanded with, or as isolated lenticles, in the 'greenstone' which forms the mass of the little island; and Messrs. Fox and Teall suggest that the flow of a submarine lava might account for these phenomena.

Lavas, diabases, and agglomerates constitute an extensive volcanic group in the Lower Silurian rocks of the south of Scotland, as pointed out by Sir Archibald Geikie, and he remarks that when the main volcanic activity came to a close, the radiolarian ooze gathered over the sea-bottom in clear, and perhaps moderately deep water.

I have already mentioned the occurrence of an important episode characterised by volcanic eruptions, during the accumulation of the Lower Silurian strata in Wales. The proof of this is that in Caernarvonshire and Merionethshire extensive interstratified sheets of felspathic lavas and ashes are associated with the rocks on two horizons, the lower that of the Llandeilo Beds, and the higher in the Caradoc or Bala Series. I do not, however, wish to imply that between them there was a complete cessation of volcanic activity, but simply that in what is now the region of North Wales, there was for a time an interval of comparative repose.[1]

Among these volcanic rocks, but especially in the Arenig, Tremadoc, and Lingula Beds below them, there are numerous dykes and bosses of greenstones (diabases, &c.), and also of more purely felspathic traps, which are not interbedded but distinctly intrusive. These give evidence of the underground working of the melted matter, the eruption of which to the surface through volcanic vents produced the lava-flows and ashes already mentioned. The ashy beds, sometimes coarse and tufaceous, were also often formed of fine volcanic dust, which, being now consolidated into hard felspathic rocks, are at first sight somewhat difficult to distinguish from the associated lavas. Practice,

[1] For further information see Ramsay, *Geology of North Wales*, 1881, and A. Harker, *The Bala Volcanic Series of Caernarvonshire*, 1889.

however, renders it comparatively easy, and the observer is aided by the circumstance, that underneath each lava-current the slates, once beds of mud, are apt to be baked and porcellanised at the point of junction with the originally hot lavas, which having in the meanwhile cooled, the slaty beds that rest on them are in that respect unaltered.

Near Bala, not far below the limestone, there are a few thin bands of volcanic ashes. These, as we go northward, gradually thicken, and by-and-by get mingled with numerous thin and thick bands of felspathic lavas, the importance of which as large masses culminates in Snowdon and the surrounding area, northward by Glyder-fawr, Carnedd Dafydd, Carnedd Llewelyn, and so on to Conway. South of Snowdon the same kinds of lavas and ashes are seen in force on the sides of Moel Hebog, and elsewhere.

Other large bosses of intrusive rocks occur between Snowdon and Conway, and in the district of Lleyn. These, ere exposure by denudation, probably were the *roots* of the volcanoes, or in other words the deep-seated centres whence the explosive force of steam drove out the lavas and showers of ashes, which, during successive eruptions, with minor periods of repose, got interstratified with the muds and sands deposited in the sea of the Llandeilo and Bala or Caradoc period.

On a smaller scale similar volcanic rocks are interstratified with the Llandeilo and Bala Beds of the Berwyn Hills, also of the Breidden Hills, where Moel-y-Golfa, as pointed out by Mr. W. W. Watts, was a centre of volcanic activity. Again, volcanic rocks occur among the strata of the hills west of the Longmynd and Stiper Stones towards Chirbury and Church Stoke, in the country between Builth and Llandegley in Radnorshire, and in North Pembrokeshire.

The next question is, what was the nature of the physical geography of this area during the deposition of the Arenig Slates, and also at a later epoch when the Llandeilo and Caradoc or Bala Beds were being deposited?

With regard to the Arenig Slates in Pembrokeshire and Merionethshire, I know of no signs of unconformity, that is to say, of a lapse of time unrepresented by the deposition of marine strata either in Pembrokeshire or in Merionethshire, unless there be some symptoms of it in the latter county. But when we go further north into Caernarvonshire, the case is different. There, at the widening of the Passes of Llanberis and Nant Ffrancon, the Lingula Flags are not more than 2,000 feet thick, whereas further south, between Ffestiniog and Portmadoc, they are at least 4,000 feet in thickness. Furthermore, in those valleys in Caernarvonshire there is, as yet, no certainty of the existence of the Tremadoc Slates, and these ought to be found overlying the Lingula Flags if the whole of the Cambrian Series were present. Still further, as we approach Caernarvon and Bangor, even the Lingula Flags are absent, and the Arenig Beds are found lying directly on the purple slates and conglomerates of the Lower Cambrian Series all the way from Bangor to Caernarvon. This clearly shows that the base of the Arenig Beds has overlapped the whole of the Tremadoc Slates and Lingula Flags, in the area between the Ffestiniog and Portmadoc country and the neighbourhood of the Menai Straits, and an overlap so great means *unconformity* between the strata; or, in other words, in this area the strata of older date than the Arenig Beds had been raised above the sea, and subjected to agencies of denudation, while the deposition of the Arenig Slates was going on elsewhere.

The effect of this episode in the physical geography of the area seems to have been, that at this period a tract of land lay to the north-west of what is now Wales, and probably far beyond that district during the deposition of the Arenig Beds on its borders, but what the features of that land were I cannot say, except that it may have extended to Ireland, where there is a similar unconformity, the Lingula Flags and Tremadoc Slates being also wanting in Wicklow. Probably the whole region was low and unimposing.

The next question that arises is, what was the nature of the physical geography during the time of the volcanic eruptions already mentioned? To me it seems to have been somewhat of this sort. On the margin of the ancient land, or at some distance therefrom, volcanic eruptions took place in the sea-bottom somewhat of the nature of that which in 1831 took place in the Mediterranean between the islands of Pantellaria and the south-west coast of Sicily.[1] In a case such as this, it is easy to see that the ordinary marine sediments of the area would get intermingled with volcanic ashes, and possibly with submarine streams of lava.

I think, then, at the time of the deposition of the Llandeilo and Bala Beds of our area, our terrestrial scenery consisted of groups of volcanic islands scattered over the area of what is now North Wales and South Wales, and extending westward into the region of the Irish strata of the same age, and northward as far as the sea that then rolled where Cumberland now stands; for there also volcanic rocks occur in great force, all of the same general character as those found in Wales. There is, however, this difference between the two areas, that, whereas in Wales ordinary sediments are plentifully interstratified with lavas and ashes, and sometimes even lithologically intermingled with volcanic ashes, in the Cumbrian area it is only for a few feet at the very base of the volcanic series that interstratifications take place, the whole of the rest of these volcanic rocks of Westmoreland and Cumberland being quite destitute of any intermixture of marine sediments. This is the Borrowdale Series, which is mainly of Llandeilo age or Lower Bala age; but at Chapel-le-dale in Yorkshire there are marine beds of green unfossiliferous slate that, according to Professor Hughes, represent the Borrowdale

[1] See Lyell's *Principles of Geology*, ed. 12, vol. ii. p. 60.

Series. Exclusive of intrusive rocks, the group consists of purely terrestrial lavas, volcanic conglomerates and ashes, the latter often well stratified, for where showers of ashes fall there layers of stratification will be formed, whether the materials fall in the sea or on land. It was suggested by Clifton Ward that some of this fine volcanic dust fell into lakes that filled old craters or areas of subsidence during periods of partial repose, and this seems highly probable, for the finely divided matter is so beautifully stratified, that these beds might be mistaken for ordinary marine strata.

When we consider the vast amount of these products of ancient volcanoes, there can be no doubt that, rising from the sea, some of them must have rivalled Etna in height, and others of the great active volcanoes of the present day. But that is all we know respecting them, and whether or not they were clothed, like Etna, with terrestrial vegetation, no man can tell. It is hard to believe that they were utterly barren, but as yet no trace of a flora has been found in Lower Silurian strata.

There is another point bearing on the physical geography of the time that has sometimes crossed my mind in connection with these island volcanoes, which is, that we may, with some show of probability, surmise, that then, as now, the prevalent winds of this region blew from the west and south-west, for the following reason. In Merionethshire and Caernarvonshire the various volcanic products gradually thin out and disappear to the west, between the ground south of the estuary of the Mawddach, and the neighbourhood of Tremadoc on the north. As we pass round the large crescent-shaped masses of lavas and ashes, it becomes evident as a rule that the ashy series of beds shows a tendency to thicken more and more in an easterly direction for a space, and finally to decrease in thickness in the same direction, till, in the Bala country and further north, it is represented only by a few insignificant beds of ashy strata, a character of which the Bala Limestone itself sometimes feebly partakes. The idea is, that the prevalent westerly winds had a tendency during eruptions to blow the volcanic dust and lapilli eastward, and that these materials fell thickest near the vents and at middle distances, and gradually decreased in quantity the further east they were carried.

To those unaccustomed to technical geological arguments a word of warning remains. Let no reader suppose that in Wales he will now find traces of old volcanic cones and craters in their pristine form, such, for example, as the extinct craters of Auvergne and the Eifel. Semicircular hollows surrounded by igneous rocks like those of Cwm Idwal and Cwm Llafar he will find plentiful enough, and these have sometimes been described as craters. So far from that being the case, such *cirques* or corries are ancient valleys of erosion, the rocks of which have been exposed to various agents of denudation perhaps ever since Upper Silurian times, and have been subsequently modified by glaciers, during the last Glacial epoch, in days, comparatively speaking, not far removed from our own. The truth about these ancient volcanoes is, that long after they became extinct the whole Lower Silurian area was disturbed and thrown into anticlinal and synclinal curves, which suffered denudations before the beginning of the deposition of the Upper Silurian rocks, and subsequently at various periods.

CHAPTER VIII.

UPPER SILURIAN ROCKS.

THE stratigraphical order of the UPPER SILURIAN SYSTEM is shown in the table p. 47. The beds were deposited under the following circumstances:—The Lower Silurian rocks in large areas in the British Islands and in some other areas, were upheaved, more or less contorted, and in many places suffered a great amount of denudation before the deposition of the Upper Silurian strata began, which, therefore, in various districts lie quite *unconformably* upon them. In

FIG. 26.—SECTION OF UPPER SILURIAN ROCKS.

4. Wenlock Limestone.
3. Wenlock Shale.
2. Llandovery or May Hill Beds.
1. *Caradoc Sandstone* (*Lower Silurian*).
8. *Old Red Sandstone.*
7. Upper Ludlow Beds.
6. Aymestry Limestone.
5. Lower Ludlow Beds.

the typical district of Wenlock and Ludlow the arrangement of the various subdivisions of these Upper Silurian strata is as shown in Figs. 26 and 30, the bands of limestone generally forming bold terraces, that look northwestward to the mountains of the Longmynd beyond Leebotwood and the beautiful valley of Church Stretton.

Notwithstanding the unconformity mentioned above, there are in Wales, and partly in Shropshire, rocks containing suites of fossils, many of them peculiar to the horizon in which they occur, and a few common to Upper and Lower Silurian. Some of these strata, such as the Lower Llandovery Beds, have been formed during minor oscillatory movements of sea and land. In South Wales, *Stricklandinia lens* occurs plentifully in these Lower Llandovery rocks, and sparingly in the Upper Llandovery rocks; while *Pentamerus oblongus* occurs sparingly in the Lower Llandovery rocks, and in great numbers in the Upper Llandovery Beds, on which rest the Tarannon Shales. In some places the Lower Llandovery rocks appear to pass into the underlying strata; in other places it is difficult to separate Upper and Lower Llandovery Beds, and they are conveniently grouped under the general name of May Hill Series, from May Hill in Gloucestershire. In this series the Tarannon Shales are included.

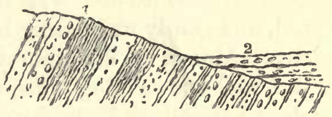


FIG. 27.—SECTION SHOWING LLANDOVERY. BEDS RESTING ON CAMBRIAN ROCKS.

2. Pentamerus-limestone and conglomerate Llandovery Beds.
1. Cambrian rocks.

In Shropshire the Upper Llandovery or *Pentamerus* Beds rest *unconformably* on the Cambrian and Lower Silurian rocks indiscriminately, and possess a beach-like character, being in places formed of pebbles derived from the rocks on which they rest, as in Fig. 27. Again, in Radnorshire near Builth, in other parts of Wales, as at Corwen (Corwen Grits) and in the Dee Valley, these strata lie with extreme unconformity, alike on the lowest and the highest Llandeilo and Caradoc Beds, as shown in Figs. 27, 28, 30. My belief, therefore, is that these LLANDOVERY BEDS, which form the true base of our Upper Silurian strata wherever they occur, were often beaches of the period; and this is further proved by the fact that they are often conglomeratic, containing rounded pebbles derived from the rocks on which they rest, while, as at May Hill and Woolhope, they are coarsely sandy.

From these facts we arrive at the conclusion that during the beginning of Upper Silurian times, part of the area now called Wales consisted of islands formed of Lower Silurian strata and volcanic rocks, round which the occasional consolidated beaches are still visible. After a time, the islands and other areas began to undergo a process of slow depression beneath the sea. If we turn to the Shropshire area between Church Stretton and Chirbury, including the ancient rocks of the Longmynd, this is what we find. On the vertical and highly inclined Cambrian and older rocks, the conglomerates and limestones of the Llandovery Beds form in the lower country a narrow fringe, surrounding great part of the area, and lying from 500 to 900 feet lower than the broad, flat-topped, and gently undulating hills of the Longmynd and Shelve. Almost on the highest level of one of these flats, at the well-known Bog-mine, there is a small outlying patch of Llandovery Beds, formed of hard quartzose sandstone, at a height of 1,150 feet above the sea, as roughly indicated in the diagram (see Fig. 28).

The inference is obvious, that these Llandovery Beds began to be deposited at the bases of the hills, and that by degrees, during a process of slow submersion, the sea crept on and on inland, accompanied by the deposition of marginal strata, till at length this old Cambrian isle was entirely swallowed up and buried, deep beneath the succeeding great accumulations of Upper Silurian strata. These in the adjoining area of Wenlock and Ludlow are more than 3,000 feet in thickness. The same fate was undergone by the Llandeilo and Caradoc rocks, that with lavas, ashes, and intrusive greenstones, now lie between Builth and Llandegley in Radnorshire. This island was, however, lower and smaller.

That these two tracts of land stood as islands in an early Upper Silurian sea, I have no doubt; and on grounds less definite, I am of opinion, that at the very beginning of the Upper Silurian epoch, the greater part of Wales, both south and north, formed land, some of it higher than now, for since that time the Cambrian and Lower Silurian rocks have undergone great and repeated denudations. As, however, the deposition of the Upper Silurian formations progressed, a steady submersion took place of the neighbouring land, from the waste of which sediments were derived; but whether or not its highest mountains were swallowed up and buried before the close of the Upper Silurian epoch I am quite unable to say. That this entire burying of the Lower Silurian rocks of Cumberland took place, seems most probable. At Austwick, near Settle, as pointed out by Professor Hughes, the base of the Upper Silurian Beds is marked by a conglomerate, which rests unconformably on the Bala or Caradoc Beds. The

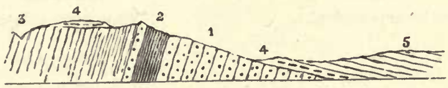


FIG. 28.—SECTION BETWEEN CHURCH STRETTON AND CHIRBURY.

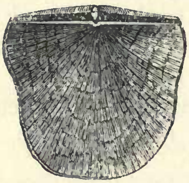
5. Wenlock Shale.
4. Llandovery Beds.
3. Tremadoc and Arenig Beds.
2. Lingula Flags.
1. Lower Cambrian grits, &c.

succeeding deposits of graptolitic mudstones and shales, known as the Stockdale Shales, belong to the May Hill Series, and higher up come the Coniston Grits and Flags of Wenlock age. In South Scotland the Birkhill Shales of the Moffat region, and the Newlands Series (grits and shales) in the Girvan district, have been shown by Professor Lapworth to be of Llandovery age. Higher up other strata, termed the Gala group, represent the Tarannon Shales, while the Riccarton Beds afford evidence of still higher rocks of Wenlock and Ludlow age.

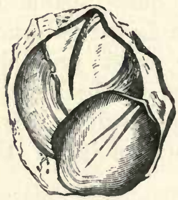
Among the fossils of the Llandovery Beds we find the Graptolites *Rastrites peregrina*, *Cyrtograptus*, *Monograptus*, &c.; and the Corals *Halysites catenularius*, *Heliolites*, and *Petraia bina*. The Trilobites include *Calymene*

Blumenbachi, *Encrinurus punctatus* ; the Brachiopods include *Atrypa reticularis*, *Orthis elegantula*, *Strophomena depressa*, *S. euglypha*, besides the *Pentamerus* and *Stricklandia*. Among Mollusca there are *Murchisonia*, *Trematonotus* (*Bellerophon*) *dilatatus*, &c.

Near Caer Caradoc and Wenlock the general section of the Silurian strata is shown in the section (Fig. 30). The



Strophomena euglypha.



Pentamerus oblongus.

Petraia bina.

Trematonotus dilatatus.

Fig. 29.—Group of Llandovery Fossils.

same kind of development occurs southward beyond Ludlow, forming beautiful scarped and wooded terraces; but beyond that into South Wales the limestones disappear, or are only very feebly represented, and the whole formation consists chiefly of shales, sometimes sandy, in which no definite lines of division for the subformations can be drawn.

Far east of this, at Usk, Woolhope, May Hill, the

Malvern and Abberley Hills, and at Dudley and Walsall, the limestone formations are well developed. Indeed, at Woolhope, near Hereford, and other places, the Woolhope Limestone is locally developed at the base of the Wenlock Beds. In North Wales the WENLOCK SERIES chiefly consists of shales and interstratified grits (Denbighshire Grits and Flags) without any bands of limestone. Near Llangollen, where the shaly strata are much affected by cleavage, they become true slate. Away in the east of England, buried beneath thick accumulations of Chalk and other strata, Wenlock Beds have been proved in a deep boring at Ware, in Hertfordshire.

All of these formations are in general terms fossiliferous. Indeed, the various palæontological horizons or 'zones'

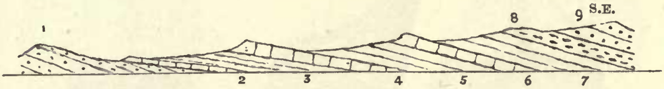


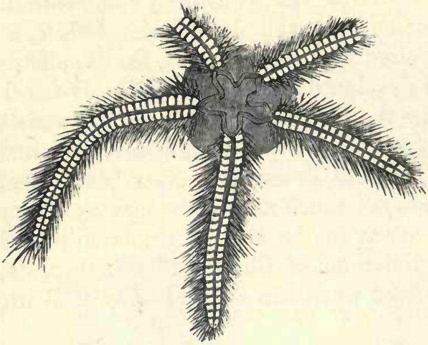
FIG. 30.—SECTION NEAR CAER CARADOC AND WENLOCK.

9. *Old Red Sandstone.*
8. Passage-beds (Downton Sandstones and Ledbury Shales).
7. Upper Ludlow Beds.
6. Aymestry Limestone.
5. Lower Ludlow Beds.
4. Wenlock Limestone.
3. Wenlock Shale.
2. Llandovery Beds, lying unconformably on No. 1.
1. *Caradoc Beds* (*Lower Silurian*).

(Nos. 2–8: Upper Silurian.)

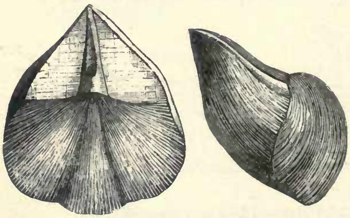
have been followed out in detail among the Upper Silurian rocks of the north of England, by Dr. H. A. Nicholson and Mr. J. E. Marr, and the same has been done for the south of Scotland in these and older rocks by Professor Lapworth. Graptolites, as before mentioned, lend the strongest aid in comparing the rocks of Britain with those of distant areas, but Trilobites also render great support.

The fossils of the Wenlock Series may be treated generally; but it should be observed that the Wenlock Limestone is in great part formed of Corals, Encrinites, and Mollusca, Corals often predominating. The Grapto-



Protaster Miltoni.

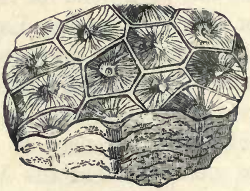
Orthoceras annulatum.



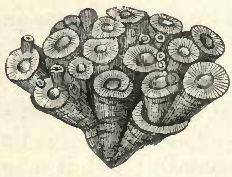
Cyrtia exporrecta.

Rhynchonella navicula.

Omphyma turbinata.



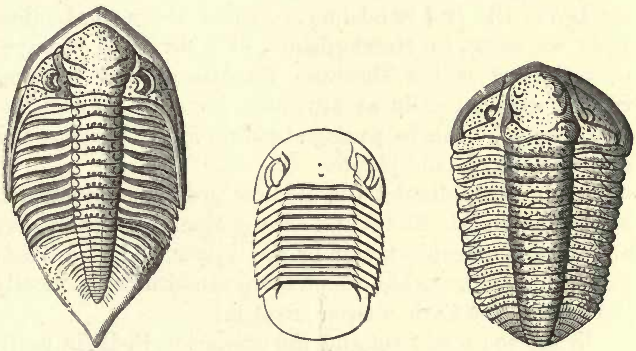
Arachnophyllum typus.



Cyathophyllum truncatum.

FIG. 31.—GROUP OF WENLOCK FOSSILS.

lites include *Cyrtograptus* and *Monograptus* ; and among the Corals we find *Omphyma turbinata*, *Arachnophyllum typus*, and *Cyathophyllum truncatum*. Another fossil is the Starfish, *Protaster Miltoni*. More important are the Trilobites, *Calymene Blumenbachi*, *Phacops caudatus*, *Encrinurus*, *Illænus barriensis*, *Homalonotus delphinocephalus*, &c. Of Brachiopods we find *Orthis elegantula*, *Atrypa reticularis*, *Strophomena euglypha*, *Rhynchonella navicula*, *Cyrtia exporrecta*, and *Pentamerus galeatus* ; and the Lamellibranch, *Cardiola interrupta*, is an important



Phacops caudatus. Illænus barriensis. Calymene Blumenbachi.

FIG. 32.—WENLOCK TRILOBITES.

one. There are various Gasteropods ; and among Cephalopods. *Orthoceras annulatum* may be mentioned. The earliest traces of land-plants were found by Dr. Hicks in the Denbighshire Grits near Corwen.

Passing on to the LUDLOW BEDS we find a group consisting mainly of shales divided by the Aymestry Limestone, a rock characterised by *Pentamerus Knighti*, but otherwise yielding many of the familiar Wenlock fossils. The Lower Ludlow Beds are of interest as yielding the earliest traces of vertebrate animals in this country—the Fish, *Scaphaspis ludensis*. Crustacea and other fossils are found, one of the most famous localities being Leintwardine in Herefordshire.

Near the top of the Upper Ludlow strata there are several thin bone-beds, containing teeth and scales of Fishes of the genus *Onchus*, also remains of *Cephalaspis*, &c. They are found in strata which contain several species of the remarkable Crustaceans *Pterygotus* and *Eurypterus*, some of which are small in size, while the largest, *Pterygotus*, discovered by Dr. Slimon near Lesmahagow, in the uppermost Silurian rocks, attained about 9 feet in length. Many of these fossils bear a close resemblance to those of the Lower Old Red Sandstone. Indeed, above the Ludlow Beds we come, in Herefordshire, to a series of passage-beds, known as the Downton Sandstones and Ledbury Shales, which, locally at any rate, serve to connect the formations. In these passage-beds we find *Pteraspis*, and also remains of land-plants.

In the Lake-district the Ludlow Beds are represented by the Bannisdale Slates and Kirkby Moor Flags, and they are overlaid unconformably by the Upper Old Red Sandstone, or Conglomerate, which there constitutes practically the base of the Carboniferous System.

In the south of Scotland the Riccarton Beds (in part), the Pentland Sandstones, and the Lesmahagow Flags, belong to the uppermost part of the Silurian System.

In the facts above mentioned there is much significance bearing on the physical geography of the next so-called geological epoch, which will be explained in the subsequent chapter. In the meanwhile, I may remark that I use the words *so-called geological epoch*, in the same sense that the words epoch or period are employed in dealing with civil or political events. Taking the geological world, and the civil world which deals with the history of man, as parallel, there is no break in time in either case. In the latter, certain remarkable events induce us to break it into periods, characterised by special circumstances, which were always led up to gradually by broad changes of power or of opinion. In the former, there are often great breaks in the chain of geological history, which, locally, are not filled up by stratigraphical deposits, and which, under these circumstances, form definite geological epochs, while in other cases (as in civil history) the change of conditions was so great in given areas, that the new series of events may be locally classed as constituting new geological epochs. This is eminently the case when we attempt to realise the history of the Old Red Sandstone as locally and physically distinct from that of the contemporaneous Devonian strata.

CHAPTER IX.

DEVONIAN ROCKS AND OLD RED SANDSTONE.

In 1837 Sedgwick and Murchison described the existence in Devonshire of a series of rocks bearing fossils intermediate in character between those of the Upper Silurian Series and the Carboniferous Limestone. Their conclusions were based mainly on the palæontological researches of Lonsdale ; but it may be said that, also on stratigraphical grounds, it was considered that the strata in question were the equivalents of the Old Red Standstone. Hence the name Devonian being applied to them, the terms Devonian and Old Red Sandstone have come to be considered as to some extent equivalents in point of geological time.

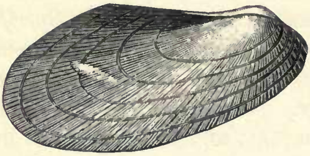
According to Jukes, the lowest strata of the Barnstaple Bay district in North Devon consist of red sandstones (Pickwell Down Sandstones) similar to those of part of the Old Red Sandstone of Ireland, and of the Mendip Hills. This, taken in connection with the resemblance of the overlying strata to the Lower Carboniferous rocks of the south of Ireland, led him to consider the chief part of the Devonian rocks of Devonshire to be of Carboniferous age. That the Upper Devonian rocks are approximately of Lower Carboniferous age is not denied. Nevertheless the opinion, that the Devonian strata are in the main the marine equivalents of the Old Red Sandstone, has been defended by Mr. Etheridge, and continues to be generally held.

In Devonshire the strata have been divided into Lower, Middle, and Upper Devonian. The Lower chiefly consists of slaty beds and red, green, and purple sandstones (Lynton

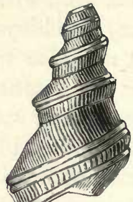
Beds, &c.), with the Coral *Pleurodictyum problematicum*, many Brachiopoda of the genera *Chonetes*, *Orthis*, *Spirifera*, &c., and also the Trilobite *Homalonotus Champernownei*. Red Sandstones, resembling Old Red Sandstone, occur at Cockington, near Torquay. The Middle group, which includes the Plymouth, Torquay, and Newton Abbot limestones, and the Ilfracombe Beds, contains numerous Corals, the most common of which are *Acervularia*, *Alveolites*, *Cyathophyllum*, *Favosites cervicornis*, and *Heliolites porosus*; there is also the Hydrocoralline *Stromatopora*. With these are found Crinoids, such as *Actinocrinus*, *Platycrinus*; and Brachiopods, such as *Spirifera Verneuili*, *Rhynchonella cuboides*, *Atrypa reticularis*, *Stringocephalus Burtini*, and *Calceola sandalina*—the last a genus peculiar to the Devonian rocks. Lamellibranchs, such as *Pterinea*, also occur, together with Gasteropods of the genera *Euomphalus*, *Loxonema*, *Murchisonia*, *Pleurotomaria*, &c.; and Cephalopods of the genera *Cyrtoceras*, *Orthoceras*, and *Gyroceras*. There are also the Trilobites *Phacops latifrons* and *Bronteus flabellifer*.

In the Middle Devonian group of South Devon there are contemporaneous volcanic rocks, named the Ashprington Series by Champernowne. These comprise fissile slaty tuffs and diabases; and, as remarked by Mr. Ussher, the volcanic materials were poured out upon a sea-bottom whereon masses of shells and corals were here and there accumulating. The beds are well shown near Totnes.

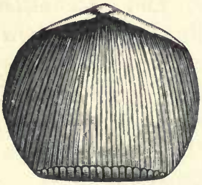
In South Devon, according to Mr. Ussher, the limestones of Middle and Upper Devonian age are inseparably connected, and with the latter he would include the Chudleigh Limestone. The Upper Devonian Limestones are characterised in their lowest stage by *Rhynchonella cuboides*, although the species occurs in the beds below. Higher up come Goniatite-beds, with *Goniatites intumescens*, *Clymenia lævigata*, &c.; and above them the Entomis-slates, with species of that Ostracod or Cyprid: beds known on the Continent as the 'Cypridinen-Schiefer.'



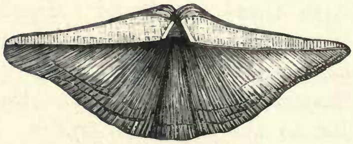
Pterinea damnoniensis.



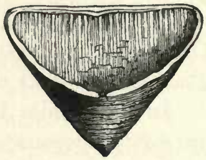
Murchisonia angulata.



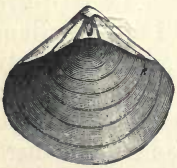
Rhynchonella cuboides.



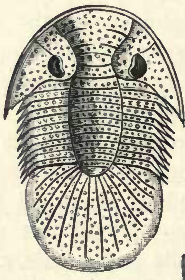
Spirifera Verneuili.



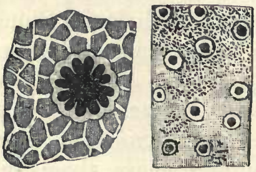
Calceola sandalina.



Stringocephalus Burtini.



Bronteus flabellifer.



Heliolites porosus.

Favosites cervicornis.

Fig. 33.—Group of Devonian Fossils.

In North Devon the Morte Slates have been considered to be an unfossiliferous group above the Ilfracombe Beds. Dr. Hicks has, however, found fossils in them, indicating a fairly rich fauna, which, in his opinion, is of Silurian aspect; and he believes that the Morte Slates form portions of the old land surface on which the Devonian rocks were laid down. So complicated are the rocks both in North and South Devon, by faults and folds, and inversions, that the structures can only be interpreted by detailed study of the rocks and their fossils.

In North Devon the beds assigned to the Upper Devonian include (in ascending order) the Pickwell Down Sandstones, Baggy and Marwood Beds, and Pilton Beds. This group contains land plants and many other fossils, some of which are identical with species found in the Lower Carboniferous rocks, including Crinoids, Polyzoa, and among Brachiopods *Chonetes hardrensis*, *Rhynchonella pleurodon*, *Spirifera Urei*, &c. The group also yields fossils found in Middle Devonian, such as *Phacops latifrons*, *Streptorhynchus crenistria*, *Spirifera Verneuili*, &c. Among characteristic fossils are *Cucullæa trapezium*, *Pterinea damnoniensis*, and *Murchisonia angulata*.

The slaty rocks known as 'killas' in Cornwall are in great part of Devonian age, and calcareous bands are met with at Newquay and other places. Rocks, however, of much greater antiquity are doubtless included in the great area of clay-slates.

Devonian slaty rocks have been proved under London at a great depth (1,066 feet), and red sandstones probably belonging to the same group have been proved beneath Crossness, Streatham, and Cheshunt.

THE OLD RED SANDSTONE, as distinct from the Devonian rocks, is undoubtedly intermediate in age to the uppermost Silurian and the lowest Carboniferous strata. It is sometimes difficult to determine its precise limits either at its base or its top. It first received its name in contradistinction to the *New Red Sandstone*, the former occurring below, and the latter above the Carboniferous strata.

A vast tract of Old Red Sandstone extends above the Silurian rocks of Pembrokeshire, Caermarthenshire, Brecknockshire, Radnorshire, Monmouthshire, Herefordshire, and Shropshire. The formation appears here and there along the Mendip Hills, and again near Bristol. The lower part is chiefly composed of beds of red marl and sandstone, with cornstones (concretionary beds of limestone); and the upper part contains strata of sandstone and conglomerate, forming the Beacons or Fans of Brecon, 2,860 feet high, these being the loftiest mountains in South Wales.

In the Lower Old Red Sandstone near Ludlow, there are species of *Pterygotus* and *Pterichthys*, and higher up, *Onchus* and *Cephalaspis Lyelli*, thus correlating them by fossils with the Lower Old Red Sandstone of Scotland (Fig. 34). Along the border of this formation, where the uppermost Silurian strata join the Old Red Sandstone, there is a gradual passage both palæontologically and in the colour and texture of the strata. The *Eurypteri* and *Pterygoti* chiefly belong to these passage-beds, and in the same rocks at the very base of the Old Red strata, in which there are no Mollusca, are species of Fishes of the genera *Auchenaspis*, *Pteraspis*, *Cephalaspis*, and *Plectrodus*. The Silurian marine Mollusca, in fact, quickly disappear where the beds begin to get red in colour, notwithstanding the perfect conformity of the two sets of strata in England and on the borders of Wales. This conformity is shown in the neighbourhood of Ludlow, and Ledbury, as pointed out by the Rev. W. S. Symonds, and in the Sawdde valley, as observed by Prof. Hughes. At Kington and south of Builth, where true passage-beds occur, the ordinary shells of the Upper Ludlow rocks and passage-beds become far less numerous, and are almost all of small size, including *Modiolopsis*, *Lingula cornea*, *Platychisma helicites*, a small *Discina*, a small *Theca*, a few small Crustacea, of the genera *Leperditia*, *Cytherellina*, &c. The water was freshening and getting unfitted for marine life.

The absence of marine shells and the nature of the fossil Fishes of the Old Red Sandstone long ago led Dr. John Fleming, and later on Godwin-Austen, to infer that the formation was deposited, not in the sea, as had been asserted, but in a great fresh-water lake, or in a series of lakes. In this opinion I thoroughly agree, for the nearest living analogues of many of the Fishes are the Polypterus of the African rivers, the Ceratodus of Australia, and in less degree the Gar-pike or Lepidosteus of North America. The red colour of the rocks also helps to the same conclusion. Each grain of sand and marl is red, because it is encrusted with a thin pellicle of peroxide of iron, which could not have been deposited from mere solution, as a crust enveloping each grain of sand at the bottom of a great open ocean; but if carbonate of iron were carried in solution into lakes, it might have been precipitated as a peroxide through the oxidising action of the air and the escape of carbonic acid.

The presence of land plants in the very uppermost Silurian strata, as, for instance, near Ludlow and May Hill, indicates the neighbourhood of land. The physical geography of the area was rapidly changing, marking the beginning of an evident Continental epoch.

The circumstances which marked the passage of the uppermost Silurian rocks into Old Red Sandstone seem to me to have been:—First, a shallowing of the Silurian sea by accumulation of sediment, aided by slow upheaval, which gradually produced a great change in the physical geography of the district, so that the old marine area became changed into a series of mingled fresh and brackish lagoons, which finally, by continued terrestrial changes, were converted into lakes; and the occurrence of a very few genera or even species of Fishes and Crustacea, common also to the fresh and brackish or even salt waters, does not prove that the Old Red Sandstone is truly marine.

In North Wales beds of red conglomerate and sandstone lie at the base of the Carboniferous Limestone of Flintshire and Denbighshire. The conglomerates contain pebbles derived from the Upper Silurian rocks. Beds of red sandstone, with bands of cornstone, form the fine escarpment of Traeth Dulas in Anglesey, where the sandstone lies unconformably on the older rocks. In the northern counties also, at Kirkby Lonsdale, Sedbergh, and Kendal, and all along the base of the Carboniferous Limestone between Orton in Westmoreland and Greystock Park in Cumberland, patches and a long line of red sandstones, marls, and conglomerates occur. These beds no doubt, to some extent, represent the Upper Old Red Sandstone, but they are usually considered as the basement beds of the Carboniferous. Among the Cheviot Hills we find a series of red sandstones and conglomerates, with interbedded tuffs and lavas (porphyrites), that may be grouped with the Lower Old Red Sandstone. They rest unconformably on Silurian (Wenlock) rocks, and are overlaid discordantly by conglomerates and sandstones (Upper Old Red Sandstone), which form the base of the Carboniferous Series.[1]

A broad belt of Old Red Sandstone crosses Scotland in a north-east direction between the Firth of Clyde and the Firths of Forth and Tay, and Stonehaven in Kincardineshire, and Montrose. Patches occur in Arran, Bute, &c. The beds lie unconformably on the old Schistose rocks, and dip to the south-east under the Carboniferous rocks that occupy the great central depression through which the Forth and Clyde chiefly run. On the south-east side of this broad undulating hollow the Old Red Sandstone again rises, and, skirting the Lammermuir Hills, strikes south-west into the sea south of Ayr. On the south side of the Lammermuir Hills it again appears in the hills between St. Abb's Head and Hawick, dipping under the Car-

[1] See J. Geikie, 'The Cheviot Hills,' in *Fragments of Earth Lore*, 1893.

boniferous rocks that, without a break, stretch from Berwick along the Pennine range to the neighbourhood of Derby.

North of Stonehaven detached patches of Old Red Sandstone occur on the mainland as far as Pentland Firth, beyond which it forms the greater part of the Orkneys, and portions of the Shetland Islands. It is seen in Aberdeenshire, and along both shores of Moray Firth, appearing near Elgin, again in the famous quarry at Eathie Burn, and in the high cliffs overlying the old Schistose rocks which form the Sutors of Cromarty. It forms some of the highlands near Golspie bordering the Dornoch Firth, and stretches a long way up the Great Valley of the Caledonian Canal, through which at one time I have no doubt it passed all the way to the Firth of Lorne, between Oban and the island of Mull. The rock forms the greater part of Caithness, where it rises in the prominent hills of Maiden Pap and Morven, and forms grand cliffs along the shore. On the west coast a large tract of hilly ground between the neighbourhood of Loch Awe, Oban, and Kerrera is chiefly formed of Old Red conglomerate and volcanic rocks.

For the first compendious account of the Old Red Sandstone of Scotland the world is indebted to Hugh Miller, whose wonderful faculty of graphic description enabled him, unassisted, to describe the rocks and the remarkable forms of life they contain, which till his time were almost altogether unknown. Something, however, still remains to be done before the precise relations to each other of some parts of the Old Red Sandstone of Scotland are clearly established. The researches of Sir Archibald Geikie and other officers of the Geological Survey have shown that, south of the Grampian Mountains, there is an upper set of strata, lying in basins unconformably on the Lower Old Red Sandstone.

Conglomerate often lies at the base of any part of the series that rests directly on the ancient slates and gneissic rocks, but occasionally thick conglomerates are intercalated among the sandy strata on various horizons, as, for example, on Moray and Cromarty Firths. These beds are sometimes thin, and sometimes of enormous thickness. Many of these conglomerates are clearly volcanic breccias and ashy beds, as, for example, on part of the Ochil Hills, south of the Firth of Tay, and from thence stretching westward at intervals to the Forth, near Bridge of Allan. The ordinary sedimentary conglomerates are frequently very coarse, containing both water-worn and subangular fragments of the underlying rocks from the waste of which they have been formed. Some of the fragments I have observed of a yard in diameter, in a mass of conglomerate that lies at the foot of the Grampian Mountains, and others, true boulders, of equal size, on the north coast of Scotland, east of Strathie in Caithness.

Some of these conglomerates possess a character which suggests that they may have had a glacial origin. The stones are of all sizes, and not mere pebbles, and they are generally sub-angular, just like those of many of the boulder clays of the last Glacial Epoch. Like some of these boulder clays also, the stones are embedded in a red marly paste, once unconsolidated clay, and in similar conglomerates in the Cumbrian region, scratched stones have been found in certain cases resembling those which had their markings produced by the agency of glacial ice. A bold man might even go further, for opposite the mouth of the valley of Ullswater, at the outlet of the lake, there are great heaps of angular boulder-conglomerate, culminating in the big mound-like hills of Mell Fell and the neighbourhood, the stones cemented in a marly base. Some of these striated stones, however, occur in the neighbourhood of faults, and may possibly have been striated during movements of the strata.

In Scotland Fishes are found in nearly all the districts occupied by Old Red Sandstone, but it was chiefly in the north, on both sides of Cromarty and Moray Firths, that Hugh Miller made his wonderful discoveries of fossil

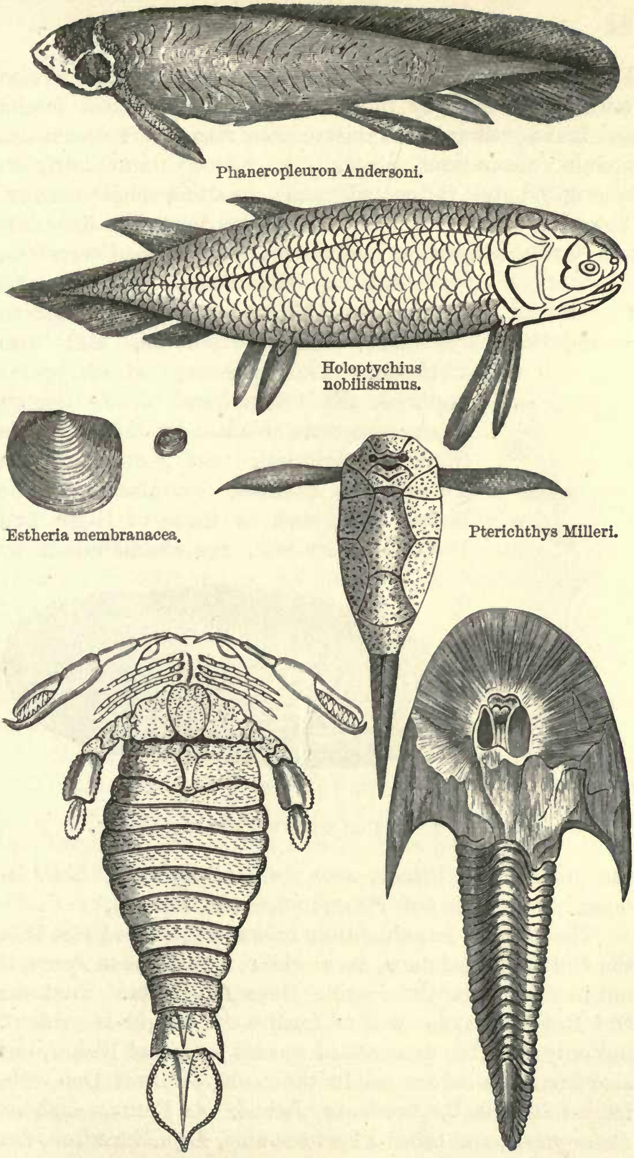
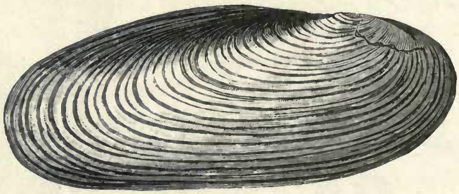


FIG. 34.—GROUP OF OLD RED SANDSTONE FOSSILS.

Fishes of many species; while in Caithness, his discoveries were followed up by those of Robert Dick. These fossils are found generally in bituminous flags with occasional nodular concretions, which lie in various minor horizons among red and variegated sandstones and conglomerates. The Fishes from these lower beds, known as the Arbroath and Caithness Flags, include many genera—*Coccosteus*, *Pterichthys*, *Diplacanthus*, *Osteolepis*, *Dipterus* and *Cephalaspis*. Besides these there are Crustacea, such as *Pterygotus*, *Stylonurus*, and *Eurypterus*, and also *Estheria*. Fine specimens of *Pterygotus anglicus*, the 'Seraphim' of the Scotch quarrymen, were obtained by James Powrie from the Arbroath paving-stone of the Turin Hill quarries, Forfarshire. The higher beds, such as those of Elgin and Dura Den in Fife, are characterised by

Palæopteris hibernica.



Anodonta Jukesi.

FIG. 35.—FOSSILS OF THE OLD RED SANDSTONE.

the presence of Fishes, such as *Holoptychius*, *Bothriolepis*, *Asterolepis* and *Phaneropleuron* (Fig. 34).

The organic remains thus indicate the broad fact that the Old Red Sandstone, as a whole, is distinct in space, if not in time, from the marine Devonian strata. That our Old Red Sandstone was of fresh-water origin is evident, not only from the presence of special genera of Fishes, but also from the occurrence in the rocks of Dura Den, of a fresh-water shell, *Anodonta Jukesi*, of Ferns, such as *Palæopteris*, and other Plant-remains, *Lepidodendron*, &c.

(see Fig. 35). The shell proves fresh-water, and the plants the vicinity of land. Such plants as we have lie, some at the base, and others near the top of the Old Red Sandstone, which, indeed, in some areas gradually merges into the Carboniferous strata, that, under varying marine and wide-spread terrestrial conditions, form the next stage of one long Continental Epoch. Nevertheless, the relations of Devonian and Old Red Sandstone are not yet clearly ascertained. There is no evidence of any barrier that could have parted the Devonian area from that north of the Bristol Channel; and Prof. Hull believes the mass of the Old Red Sandstone of Hereford was estuarine, and equivalent to much of the marine Devonian.

When all the foregoing statements are fairly considered, it seems to me that we obtain sufficient material from which to form a conception of the physical geography of our area during the deposition of the Old Red Sandstone; as follows:—

In a mountainous region of which the Scandinavian chain formed part, the lakes of the Old Red Sandstone epoch lay; for patches of these strata opposite Scotland, and bordering the sea, lie on the Norwegian coast. What was the extent of the Great Lake in which the central Scottish strata were deposited I am unable to say, for they strike out to sea in the Firth of Clyde on the west and to the North Sea on the east coast. Whether or not the Old Red Sandstone of this area was originally united to that which borders the Firths of Moray and Dornoch, and also to the flags and sandstones of Caithness and the Orkneys, I cannot tell, though it has been usually stated that the eastern side of the older Highland rocks was continuously fringed by Old Red Sandstone. It seems to me, however, to be not unlikely, that as the great Grampian range south of the Dee even now attains to heights of about 2,000 feet in Kincardineshire, in older times, having suffered much less from denudation, it was higher than now, stretched further east, and probably formed an effectual barrier between two lake-areas in which Old Red Sandstone was deposited. But even if the red sandstones of the whole of Scotland were once united to those of the coast of Norway, in one continuous stretch of inland water, it is not without parallel at the present day, for the brackish Caspian lake occupies a larger area, and it has been said that even in historical times the Caspian was larger than now.[1] The great fresh-water lakes also of North America, from Lake Superior to Lake Erie, exclusive of Ontario, occupy an area far larger than the whole of Scotland with all its islands.

When we try to realise the kind of scenery of this old period, we are led to something of this kind. The lake or lakes were more or less encircled by high mountains, and on the banks, and perhaps as occasional islands, volcanic cones disgorged streams of lava and discharged showers of ashes and stones, to be interstratified with the ordinary sediments. At the same time, from the lofty mountains that now form the Highlands, but higher then, glaciers descended into the water, and fleets of icebergs floated hither and thither, and, melting, dropped their moraine matter to intermingle with other sediments, while further south, in Cumbria, similar glaciers may have descended from the ancient mountains, higher and different in form from those of modern date in the same area.

In a region still further south, we come to the lake in which the Old Red Sandstone of South Wales and the adjoining counties was deposited. These strata certainly spread further north and west than the edge of the main mass does now, a fact shown by the large outliers in Montgomeryshire. Away in the distant west, rose the lofty mountains formed in part of the far more ancient Lower Silurian rocks of North Wales, but no contemporaneous volcanic rocks are anywhere found among the Old

[1] See A. Geikie, On the Old Red Sandstone of Western Europe, Part 1, *Trans. Roy. Soc. Edin.* vol. xxviii. p. 345, 1878.

Red Sandstone strata that were deposited in the adjacent lake, the eastern shores of which were, I think, low and unimposing.

Again, we may suppose a set of circumstances such as the following :—If, by changes of physical geography of a continental kind, a portion of the Silurian sea got separated from the main ocean, more or less like the Caspian and the Black Sea, then the ordinary marine conditions of the 'passage-beds,' accompanied by some of the organisms of the period, might be maintained for what, in common language, seems to us a long time. The Black Sea was once united to the Caspian, and the Caspian to the Aral, forming one great inland sea, which, under varying physical conditions, has more than once changed its form and extent. At all events, since its separation from the Black Sea the Caspian has been simply a great brackish lake. The Black Sea is now steadily freshening; and it is easy to conceive that by a geographical change, such as the upheaval of the Bosphorus, it might be converted into a fresh-water lake, if the supply of river water were sufficient to overbalance evaporation and secure an overflow. The marine forms would long linger in the deeper parts of the lake, which would only slowly change its character from salt to fresh water; and some of the marine species might slowly adapt themselves to the altered conditions and might survive when the lake became entirely fresh. At present a great body of salt water is constantly being poured out through the Bosphorus, and its place taken by the fresh water of rivers. Owing, however, to the uncongenial quality of the freshening water, some of the Black Sea shells are strangely distorted, as observed by Edward Forbes.

If by increase of rainfall the Caspian became freshened, the loss of water by evaporation not being equal to supply, it would by-and-by, after reaching the point of overflow, be converted into a great fresh-water lake, larger in extent than the whole area now occupied by the British Islands and the Irish Sea. It is even conceivable that the great area of inland drainage of Central Asia, now holding many salt lakes, might in the same manner be so changed that all its lakes would become fresh and widened in extent, thus occupying areas larger than all the Old Red Sandstone of Europe. Under these circumstances, in the Caspian area we should have a passage more or less gradual from imperfect marine to perfectly fresh-water conditions, such as I conceive to have marked the advent of the Old Red Sandstone. When the whole area was fairly separated from the sea, the sediments might by degrees get into a condition to be coloured red in the manner previously mentioned.

The uniformity of action here sketched may present a difficulty to some geologists, seeing that on the borders of South Wales the Upper Old Red Sandstone, over a large space, overlaps the lower strata till it lies directly on Lower Silurian rocks, and the same is the case in parts of Scotland. It has been suggested that this great overlap was attended by unconformity, and that it marks the interval during which elsewhere the main portions of the marine Devonian strata were accumulated. But on consideration these circumstances do not present any real difficulty. If the great hollow in which the Dead Sea lies, were gradually to get filled with fresh water, and the whole by degrees became silted up, 1,300 feet of strata would be added above the level of the present surface, and the upper strata all round would overlap the lower, apparently much as the Old Red Sandstone strata do in Wales and the adjoining counties. If the Caspian and other parts of the Asiatic area of inland drainage were filled with fresh water, the same general results would ensue.

Like the recurrent circumstances that have attended the rise and fall of empires through all historical time, so geological history has often more or less repeated itself, somewhere or other on the surface of the earth; and in this modern phase of Asiatic physical geography, it seems to me that we may have, so far as it has gone, a repetition of events, which, with minor variations, have happened again and again in old-world geological epochs. The farther off geological records recede, like inscriptions in an unknown tongue, the more difficult are they to decipher; the nearer they come to our own day, they are often more easy to read.[1]

[1] Those interested in this subject may consult Hull, *Physical History of the British Isles*, 1882; and Jukes-Browne, *Building of the British Isles*, ed. 2, 1892.

CHAPTER X.

CARBONIFEROUS ROCKS.

In the south and middle of England, the Carboniferous Rocks consist chiefly of Limestone at the base and Coal-measures above. Including South Wales, the Forest of Dean, the Mendip area and Bristol, and extending northwards to Flintshire, Lancashire, Derbyshire, and Yorkshire, the general succession of the beds is as follows :—

	Feet		Feet
Coal-measures	1,000	to	8,000
Millstone grit	500	,,	2,000
Yoredale rocks or Upper Limestone shale .	100	,,	1,500
Carboniferous or Mountain Limestone .	500	,,	2,500
Carboniferous or Lower Limestone shale .	100	,,	500

In the southern parts of this region the beds rest conformably on the Upper Old Red Sandstone; indeed there is in places a gradual passage upwards from that formation into the Lower Limestone Shales. In North Wales and other parts the Upper Old Red Sandstone, as before mentioned, is represented only by conglomeratic beds that form a natural base to the Carboniferous Series.

The Lower Limestone Shales, well seen in Pembrokeshire, in the Avon gorge, and on the Mendip Hills, yield numerous Fish-remains ; also Trilobites of the genus *Phillipsia,* and Crinoids. Brachiopods are more conspicuous, and they include *Athyris Royssii, Rhynchonella pleurodon, Orthis resupinata, Spirifera,* &c. The Carboniferous Limestone is so highly fossiliferous that it may be stated that the main mass once formed parts of organisms,

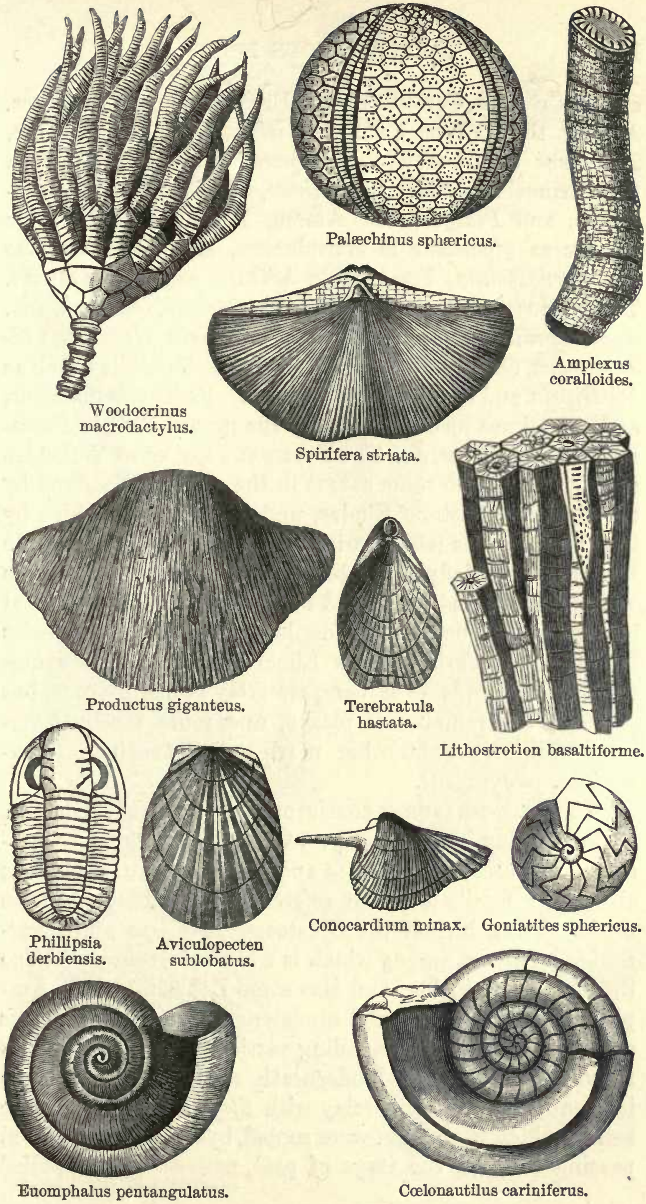


FIG. 36.—GROUP OF CARBONIFEROUS LIMESTONE FOSSILS.

chiefly Crinoids, Corals, Polyzoa, Brachiopods, and Molluscs. Among the Corals we find *Lithostrotion basaltiforme*, *Amplexus coralloides*, *Syringopora*, and *Cyathophyllum*. The Crinoids include *Palæchinus*, *Woodocrinus*, *Cyathocrinus*, and *Platycrinus*. Among Brachiopods the large *Productus giganteus* is conspicuous, and there are also *Spirifera striata*, *Terebratula hastata*, and many others. The Mollusca include *Posidonomya Becheri*, *Conocardium*, *Aviculopecten*, *Euomphalus*, *Pleurotomaria*, *Goniatites biangulatus*, *G. Listeri*, and *Cœlonautilus*. Trilobites such as *Phillipsia* and *Griffithides* are found. Fish-remains occur, and sometimes form bone-beds; the genera include *Psammodus*, *Cochliodus*, &c. The YOREDALE ROCKS of Yorkshire are represented to some extent in the south of England by the Upper Limestone Shales, and in Glamorganshire by the Gower Series (shales with sandstones). The Yoredale Beds consist chiefly of shales and sandstones, with bands of limestone; and they yield marine shells and occasional land-plants. The marine fossils mostly belong to species found in the Carboniferous Limestone. The MILLSTONE GRIT in most places is comparatively unfossiliferous, but contains the remains of plants, and more rarely *Orthoceras*, *Goniatites*, and other marine shells, such as *Aviculopecten papyraceus*.

The COAL-MEASURES consist of alternations of sandstone, shale, fireclay or underclay, coal, and ironstone. Occasional Mollusca, *Anthracosia* and *Anthracomya*, are found; also other fossils to which reference will subsequently be made. These include the Crustacea *Belinurus* and *Prestwichia*; Insects, among which is a kind of Cockroach; also Spiders, many Fishes, and also some Labyrinthodont Amphibia. In the shales and sandstones large stems of plants are sometimes found standing vertically, in the positions in which they grew. Underneath each bed of coal there is usually a bed of underclay with *Stigmaria*, forming the soil in which the plants were rooted, by the decay of which, passing through the stage of peat, material was supplied

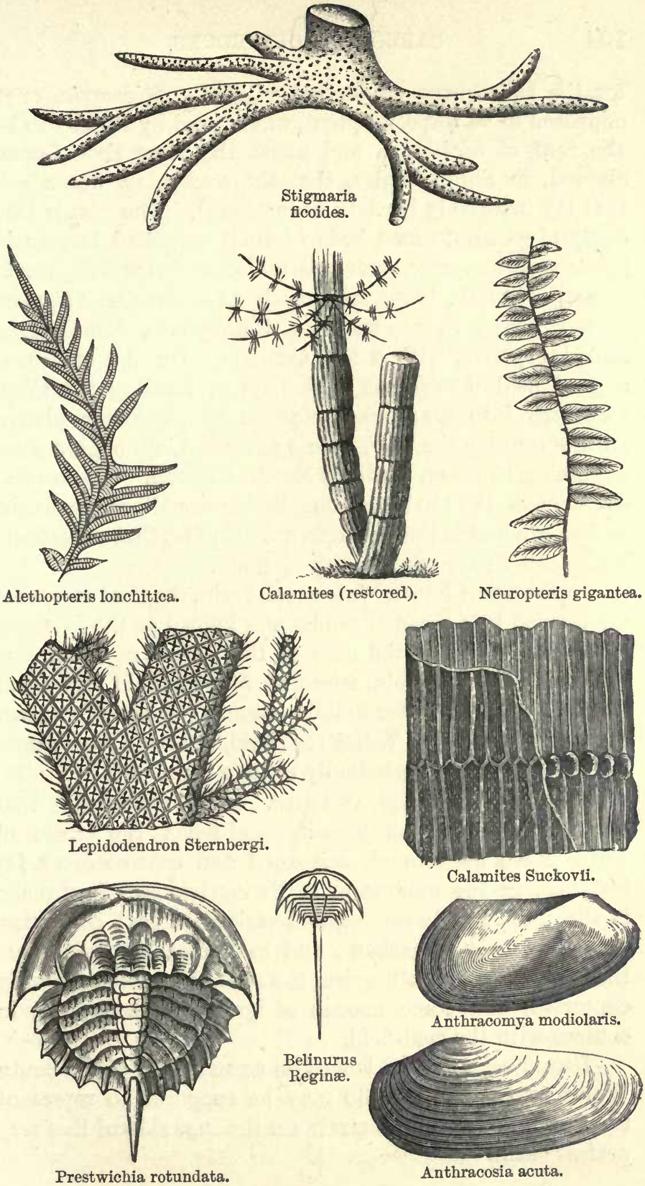


FIG. 37.—GROUP OF COAL-MEASURE FOSSILS.

for the subsequent production of coal. *Stigmaria*, once supposed to be a special plant, was proved by Binney to be the root of *Sigillaria*, and about the same time Logan showed, in South Wales, that the *underclay* was a soil that lay invariably beneath beds of coal. The plants (the decay of which formed beds of coal) consisted largely of gigantic club-mosses, such as *Lepidodendron* and *Sigillaria* (*Lycopodiaceæ*); horse-tails, such as *Calamites* (*Equisetaceæ*); many Ferns, such as *Alethopteris*, *Neuropteris*, and *Pecopteris*, with a few Conifers. On the continent a good deal of work has been done in dividing the Coal-measures into zones characterised by particular plants. In this country the work is less advanced, although a good beginning has been made by Mr. R. Kidston. The several divisions of the Carboniferous Series are all conformable, and so gradual is the passage in most cases that no definite limits can be assigned to any of them.

In the great South Wales coal-basin, the Coal-measures are divided by a mass of sandstones known as the Pennant Grit. The same is the case in the Forest of Dean, and in the Bristol coal-field, where at Mangotsfield and other places it is quarried for building-stone. Passing from east to west in the South Wales coal-field, the coals (sometimes the very same beds) gradually change from so-called bituminous to anthracitic varieties. It is remarkable that anthracite usually occurs in coal-fields the strata of which have been much disturbed and contorted, as, for instance, in the mountains of Pennsylvania. Anthracite is the most highly mineralised variety of coal, consisting almost entirely of carbon; and in Pembrokeshire, where the coals are most anthracitic, the strata have been violently contorted, and some masses of igneous rocks appear in contact with the coal-field.

Dean Forest may be looked on as an outlier of the South Wales coal-field. Fig. 38 may be supposed to represent the arrangement of the strata on the east side of this very perfect basin.

The Coal-measures and Millstone Grit of the Bristol and Somersetshire coal-field lie in a basin, the base of which is formed of the Carboniferous Limestone. A large part of this basin is unconformably covered by New Red Marl, Lias, and Oolitic strata, but here and there portions of the coal-field are exposed by denudation between Bristol and the Mendip Hills, where the beds rise rapidly, and skirt the Mendip limestones, the whole dipping north at high angles. Indeed, the strata are in places so highly disturbed, that Coal-measures have actually been worked beneath Carboniferous Limestone near Vobster (see p. 21). Coal-measures probably underlie the marshes, and the Secondary strata south of the anticline of the Mendip Hills. An

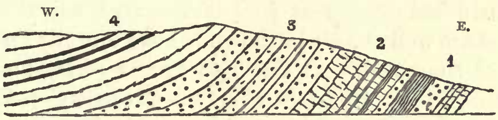


FIG. 38.—SECTION IN THE FOREST OF DEAN.

4. Coal-measures, with seams of coal.
3. { Millstone Grit. / Upper Limestone Shale.
2. { Carboniferous Limestone. / Lower Limestone Shale.
1. Old Red Sandstone.

exposure of the Carboniferous Limestone occurs westwards at Cannington Park, near Bridgewater.

The three coal-basins of South Wales, Dean Forest, and Bristol, once united, have been separated by denudation similar to that shown at p. 28. In the case of these coal-fields the intervening spaces are anticlinal, and the basins synclinal curves, and therefore it was suggested by De la Beche and Godwin-Austen that other coal-basins may lie far to the east beneath the Oolitic, Cretaceous, and Eocene strata of the London basin. Lower Carboniferous rocks have been proved beneath the Cretaceous strata at Harwich; Coal-measures have been reached beneath the Oolites and Lias at Burford, in Oxfordshire, and more recently beneath the Cretaceous rocks and Oolites at Dover.

The Culm-measures of Devonshire, though of true Carboniferous age, and probably representing much of the coal-series, are nearly unproductive. They, too, were at one time connected with the South Wales area. Near their base there are impersistent bands of limestone, which may feebly represent part of the great masses of Carboniferous Limestone of Somerset and South Wales, just as the thin worthless coals (or beds of culm) may represent some of the seams of those coal-fields. The Limestones contain *Posidonomya Becheri* and *Goniatites*. The conditions of deposition in the areas were apparently very different; for in the Devonshire area the purely terrestrial intervals, marked by the growth of land plants *in situ*, seem to have been infrequent and transitory, and from bottom to top sandy and clayey strata prevail. The strata are remarkably disturbed over great part of the area, and these contortions are well shown in the cliffs near Clovelly and other parts of the coast. At the base of the series, above the limestones, there occur the cherty beds of Coddon Hill.

Evidences of former volcanic activity are found, and Brent Tor, near Tavistock, is considered by Mr. F. Rutley to be one of the best preserved of our ancient volcanic vents, though the eruptions took place in early Carboniferous times. Lavas and ashy beds are there interstratified with the Culm-measures, and Brent Tor marks the site of an eruptive vent.

In the neighbourhood of Newent, narrow bands of poor Coal-measures are barely traceable between the Old Red and the New Red Sandstones, and still further north, round Bewdley, there lies the coal-field of the Forest of Wyre, consisting of strata by no means very productive of coal. They lie directly on the Old Red Sandstone, the Carboniferous Limestone being absent. The Coalbrookdale coal-field joins that of the Forest of Wyre, and lies partly on a thin development of Carboniferous Limestone, and partly unconformably on Upper Silurian rocks. It contains several bands of good nodular ironstones, which often yield fossils, including Ferns, Insects, and Crustacea. Of Crustacea the genus *Prestwichia* is allied to the recent king-crabs. A band of limestone in the upper part of the Coal-measures is characterised by the Annelid *Spirorbis pusillus*, and is known as the *Spirorbis*-limestone.

The North Wales coal-field in all essential points resembles that of South Wales. The upper division of the Carboniferous Limestone is a black limestone with *Posidonomya Becheri*, and *Goniatites*, suggesting comparison with the limestones at the base of the Culm-measures in Devon. A similar rock occurs in the Isle of Man. In North Flintshire the Carboniferous Limestone is overlaid by remarkable 'chert-beds' which are grouped with the Millstone Grit. These beds are described by Mr. A. Strahan, who observes that the chert is probably a siliceous sediment of extreme fineness. A small fragment of Coal-measures occurs in the central part of Anglesey. It is underlaid by the Carboniferous Limestone, and on the south-east is faulted against the older schistose rocks. Permian strata overlie it, but the smaller faults and a greenstone dyke which affect the coal do not pass through the Permian beds, which lie unconformably over all.

In the centre of England the basement beds of the South Staffordshire coal-field rest directly on the Wenlock Limestone. In the Dudley district a number of coal-seams that are separated to the north coalesce to form the famous 'ten-yard' seam, which in places is more than thirty feet thick. The rocks are pierced by basalt, which has charred the coals at the points of junction, and is undoubtedly connected with the great basaltic mass, called the Rowley Rag, that overlies the Coal-measures. To the east comes the Warwickshire coal-field, bordered, between Nuneaton and Atherstone, by the quartzites of Hartshill and the shales of Stockingford, now known to be Cambrian.

The Ashby-de-la-Zouch coal-field is overlaid by the New Red Sandstone, and partly underlaid by the Carboniferous Limestone, and partly, probably, by a continuation of the old rocks of Charnwood Forest. The Coalbrookdale, South Staffordshire, and Warwickshire coal-fields present so many points of resemblance, that undoubtedly they were all originally formed as one coal-field, and even now in great part may be continuous in the districts that lie between, concealed by Permian and New Red strata.

North of these coal-fields the Carboniferous rocks are somewhat modified in details. Between Derbyshire and Berwick they stretch north and south without a break along the Pennine range. At the southern end, near Derby, the New Red Sandstone overlies them. West of Cheadle, along the edge of the North Staffordshire coal-field, they are generally faulted against the Permian rocks, north of which lie the coal-fields of Cheshire and Lancashire. The Carboniferous Limestone and Millstone Grit rise between these coal-fields, forming the higher hills of Derbyshire; and the Coal-measures are thrown off on either side of the anticlinal axis, forming, in the east, the Derbyshire and Yorkshire coal-field, and on the west those of North Staffordshire, Cheshire, and Lancashire. Two or more beds of contemporaneous dolerite, called toadstone, lie in the Limestone. The Millstone Grit of these areas is much mingled with shale, and between it and the Carboniferous Limestone there are often thick beds of shale and sandstone, called the Yoredale rocks. All these are ironstone areas, and North Staffordshire is the great pottery district of England. The finer clay is imported, only the coarser qualities for tiles, &c., being obtained in the district.

North of the Ribble the Carboniferous Limestone itself is divided in places by numerous interstratifications of sandstone and shale, with occasional beds of thin coal, and this increasing in the northern parts of Northumberland, the equivalents of the southern mass of Carboniferous Limestone die away into a few subordinate beds of limestone, and fairly pass by degrees into a lower coal-field, with several beds of coal. In this northern area the divisions made in the centre and south of England are no longer applicable. The basement portion of Northumberland is usually termed the Tuedian group (from the Tweed valley), and it corresponds to some extent with the Calciferous Sandstone of Scotland.

In Northumberland, as already stated, we find a lower coal-field of the age of the Carboniferous Limestone series, and the Berwickshire coals of Scotland are of the same general age; but the main coal of the Newcastle district belongs to the true Coal-measures. There is another much smaller coal-field near Ingleton in North Lancashire, and in Cumberland the Whitehaven Coal-measures lie on the Carboniferous Limestone, and at Workington coal has been worked for some distance beneath the sea.

Intruded among the Lower Carboniferous rocks of Northumberland, Cumberland, and Durham is the Great Whin Sill, an eruptive sheet of diabase, which alters the beds both above and below it. Mr. Topley and Professor Lebour have shown that it occupies various positions in the Carboniferous Limestone series, but it may have been formed at the close of the Carboniferous period. It is well shown at the waterfalls of Cauldron Snout and High Force in Teesdale.

The great Scottish coal-fields lie in a broad synclinal curve, in which are the valleys of the Clyde and Forth. Beneath the Calciferous Sandstone and Carboniferous Limestone series, Old Red Sandstone, underlaid by Silurian rocks, rises on the south-east between St. Abb's Head on the east and Girvan on the west; while on the north-west the Old Red Sandstone resting on the older rocks of the Highlands, rises from beneath the same Carboniferous strata between the Firth of Tay and the Clyde, near Dumbarton.

The Lower Carboniferous strata of Scotland contain some contemporaneous eruptive rocks, such as basalts, porphyrites, trachytes, and also tuffs and agglomerates, which sometimes contain organic remains. Examples of these rocks are well seen in the cliffs between Dunbar and Belhaven. The limestones, which overlie the Calciferous Sandstone, do not lie in a mass at the base of the Coal-measures, but, as in the North of England, occur in several beds, chiefly in the lower part of the Carboniferous Limestone series, interstratified with beds of sandstone, shale, and occasionally of coal. Many Corals have been obtained by Mr. James Thomson from these limestones. In Linlithgowshire and the Campsie Hills limestones are interbedded with lavas and tuffs; and in some localities, as noted by Sir Archibald Geikie, the tuffs contain remains of plants and marine organisms. Marine, fresh or brackish water, and terrestrial alternations are of constant occurrence in this series of strata. In some cases in East Lothian, beds of fireclay, with *Stigmaria*, and thin layers of coal lying on old terrestrial soils, immediately underlie marine limestones with *Productus*. In the Dalkeith coalfield valuable beds of coal with shales are interstratified with a thick series of limestones. The Burdiehouse brackish water limestone in East Lothian is the lowest of the limestones, and yields many small bivalve Crustacea of the genus *Estheria*, besides Fishes, such as *Megalichthys* and *Rhizodus*. Remains of Labyrinthodonts have also been found.

The Carboniferous strata of the Lothians cross the Firth of Forth beneath the sea, and form great part of Kinross and Fife. The western part of the basin in Lanarkshire and Ayrshire yields the well-known black-band ironstones and oil-shales. The famous Torbanite or Boghead Coal, found in Linlithgowshire, is a variety of cannel coal that has been largely used for the manufacture of gas and paraffin oil.

I have already said that many of our coal-fields originally formed one, and have been separated by disturbance of the strata and subsequent denudation. The same kind of original continuity may be inferred concerning all the coal-fields of the middle of England, North Wales, and perhaps northward to Cumberland and Northumberland, and even the latter was probably joined to the great coalfield of central Scotland. After the close of the Carboniferous epoch, this large area was also thrown into a series

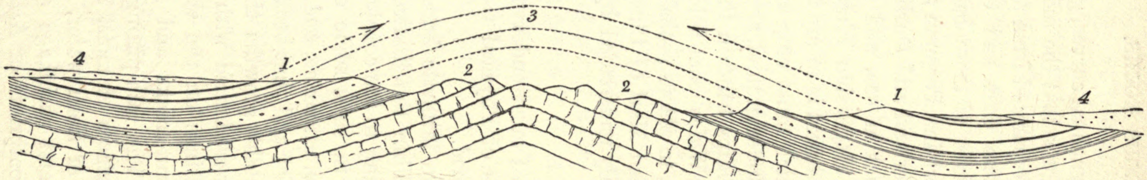


FIG. 39.—DIAGRAM SHOWING THE ORIGIN OF THE BASIN-SHAPED FORM OF MANY COAL-FIELDS.

1. Coal-fields showing at the surface in part. 2. Carboniferous Limestone. 3. Anticlinal curve between the two Coal-fields, which were once joined. 4. Permian and New Red strata covering parts of the two basin-shaped Coal-fields.

of undulating anticlinal and synclinal curves, great denudations occurred, and the result was that the individual coal-fields now lie in basins often separated from each other by intervening tracts of Millstone Grit and Carboniferous Limestone. Sometimes portions of these basins are concealed by unconformable overlying Permian and New Red strata. Thus, the Northumberland and Durham coal-field is probably a basin, partly out at sea, and the southern edge of which is overlaid by Magnesian Limestone. The Yorkshire and Derbyshire coal-field is in my belief another basin, the eastern half of which must crop up against the Magnesian Limestone, deep under ground, and many miles to the east of where it first dips beneath that limestone. The Lancashire and North Wales coal-fields also form parts of another great basin, in places probably 6,000 feet or more beneath the New Red Marl of Cheshire. These statements will be more easily understood by referring to Figs. 39 and 115.

Before closing the subject I must endeavour to explain under what broad conditions of Physical Geography the Carboniferous series was formed.

It is impossible to have an intimate knowledge of the Carboniferous rocks, even within the limited area of the British Islands, without coming to the conclusion that the various strata were formed in seas, some comparatively open and deep, some shallow, estuarine, and restricted in area, and some in fresh water; and that beds of coal were due chiefly to terrestrial vegetable growths that flourished and died on the land, and were buried with the soils on which they grew. Rain-pittings on the shales are not infrequent, together with sun-cracks and footprints of Labyrinthodont Amphibia. The rain-pittings in this case tell of showers falling on surfaces of moist mud, exposed by the temporary retirement of fresh water, and the sun-cracks indicate the drying and shrinkage of that mud; and these joined with the footprints of Amphibia tell of daily events which by happy accidents got perpetuated, first, by baking in the sun's rays. Next, when the area was again overflowed, new layers of mud settled on these impressions, and afterwards became consolidated into shale; and thus we have, in a measure, fossilised sunshine, showers, and footsteps of old Amphibians, imprinted, during their occasional visits to the moist land, on the margin of the water in which they chiefly lived.

The Carboniferous Limestone is of exceedingly variable thickness. In parts of South Pembrokeshire, it is about 2,500 feet thick. Going north to Haverfordwest it rapidly thins out, and finally disappears by overlap in a distance of twelve miles. A rapid thinning of the same strata also takes place between the shore of the Bristol channel in Glamorgan and the north side of the South Wales coal-field. In the Mendip Hills the Limestone again has a thickness of about 2,500 feet. Among the limestone hills of Derbyshire it is of enormous thickness, and its base is unknown; but so indistinct is the bedding in part of the centre of that region, that it is often as hard to make out the details of stratification as it is in a large consolidated modern coral reef. North of Clitheroe the bosses of limestone are in places remarkably massive, and thin away in various directions so rapidly, that one is tempted to imagine faults where none exist. Mr. Tiddeman believes that such bosses represent old coral-reefs, and a similar explanation has been given by M. Dupont of the knolls and mounds in the Belgian Carboniferous Limestone. It is possible, however, that in both cases these bosses may be better explained by sharp foldings of the strata.

The prevalence of corals in some of the thick masses of Carboniferous Limestone, and sometimes the rapid thinning out of these masses in opposite directions, point to the conclusion that they were true coral reefs, of the nature of the Barrier Reefs of Australia and the Pacific Ocean, and that they thinned away on one side to a feather edge in the direction of the land, and on the other more steeply towards the deep sea. These lenticular masses were probably formed round outlying islands, large and small, undergoing a process of slow depression, or otherwise on the shores of some old continent, the details of the original shape of which are now lost to our knowledge. One part of this land, however, consisted of that area now known as the mountainous parts of Wales, and the adjacent Silurian and Cambrian territory that underlies the Coal-measures of the Midland counties, Cumbria, and the South of Scotland, while far north the Grampian mountains and the whole of the North Highlands stood higher above the level of the sea than they do now, for ever since they have suffered denudation.

While in the south, coral-reefs of the nature of Barrier Reefs or Atolls were being formed, in the north the case was different. There, as in parts of the modern Pacific, volcanic action was rife, and this is witnessed by the lavas and ashes, intermingled and interstratified with the Carboniferous series in Scotland. This area, together with the north of what is now England, was therefore more or less an area of elevation, accompanied by oscillations of partial depression. Thus it happens that in these regions, the bands of Carboniferous Limestone are quite insignificant when compared with the thick interstratifications of shale and sandstone with occasional beds of coal that lie between them, and which, excepting the beds of coal, were of ordinary aqueous sediments.

This naturally leads to the question under what circumstances were the purely mechanical sediments and the beds of coal formed? The answer is, that after the close of the Carboniferous Limestone epoch in the south, the area got filled up by the sands of the Millstone Grit and the more muddy strata (now shales) that overlie them, and this shallowing of the seas may have been aided by partial upheaval of the area, till much of it was a little above the level of the sea. Through this flat portion of the continental land, great rivers ran, bordered by wide marshy flats, on which grew the vegetation that on decay became transformed into a kind of peat. Then by gradual depression these areas were again covered with water, in the first instance salt or fresh, as the case might be, but in all cases resulting in the deposition of layers of sediment. The area was thus converted by degrees into low land, covered by vegetation, a new growth and decay took place, and it was again depressed beneath the water to receive newer sediments. So on through a vast period of time, till, for example, all the 10,000 feet of the South Wales coal-field were accumulated, interstratified with the numerous beds of coal, great and small, that lie among the shales and sandstones; and in equal or less degree the same was the case with all the other coal-fields of England and Wales, as far north as those of Lancashire and Yorkshire. Some beds of coal, as pointed out by Professor Green, were formed of vegetable matter that was drifted into shallow ponds or lakes, and there reduced by soaking to a pulp. Cannel coal may have been formed in this way, for it frequently contains Fish-remains.

When we come to other Carboniferous areas, further north, in Durham, Northumberland, and Scotland, we find no thick masses of limestone, but only thin bands, interstratified with thick deposits of shale and sandstone, similar in most respects to those of the Coal-measures of Wales, and, like these, interstratified with beds of coal, each underlaid by its terrestrial soil of underclay with *Stigmaria*. These fluvio-marine areas were contemporaneous with the purely marine areas of the Carboniferous Limestone of the south. In the north, however, the close association of limestone, containing marine fossils and indicating clear water, with beds of coal and underclays, is at first sight a puzzling fact. It may be due to rapid changes of level, but a more probable explanation is that suggested by Sir Archibald Geikie, that the large areas of coal-growth stopped the flow of sedimentary material to the sea, and allowed clear water to lie close to the shore. As the area sank, the coal-growth passed beneath the sea and was covered up by marine limestone.

Considering the magnitude of the areas which the beds of coal cover, they bear witness to the existence of a vast continent, through which wandering rivers traversed extensive flat areas, comparable to those of the largest alluvial plains of the world. Deltas of the present day offer many analogies. The mouth of the Hoang-ho or Yellow river is now 250 miles north of the place where it entered the sea about forty years ago. The modern delta of the Mississippi has an area of more than 12,000 square miles, consisting chiefly of sands and clays, with much vegetable matter, and that of the Nile an area of about 21,000. The delta of the Ganges and Brahmapootra now more than 48,000 square miles in extent, has peaty beds interstratified with clays and sands, often much below the level of the neighbouring sea. The area of all the coal-fields of Great Britain extended to their original size did not equal that of this great delta.

It is not to be supposed that, in each coal-field, every bed of coal extends over the whole area. On the contrary, they thicken and thin out, and have their edges like many a modern peat moss. The vegetation of the Carboniferous epoch flourished and decayed rapidly, on moist ground and in a moist atmosphere, not of excessive warmth, as has often been stated, but, in the opinion of Sir Joseph Hooker, 'in a moist and equable climate,' that could scarcely have been sub-tropical.

CHAPTER XI.

PERMIAN STRATA.

In England there are certain red strata, known as Permian, which occupy a sort of debatable ground, lying between the Carboniferous and New Red or Triassic series. Sometimes they have been classed with the former, sometimes with the latter, by those who like to insist on hard and fast lines of division between each formation. These strata, though in this country lying by no means conformably either with the underlying or overlying formations, may be considered as in some sense transition beds. They mark one of the steps in that change of the physical geography of our area which put an end to the development of Coal-measures, and made it possible under new conditions for the great series of Permian and New Red strata to be deposited.

The higher beds in certain areas consist chiefly of Magnesian Limestone or Dolomite, interstratified with red marls; and the lower comprise red marls, sandstones, and conglomerates. But this division does not everywhere hold good, for in the north-eastern part of England the Magnesian Limestone often lies directly on the Coal-measures, and in Lancashire and the Vale of Eden, in the north, only a few thin beds of Magnesian Limestone lie in the middle of a thick series of red sandstones and marls. Hard and fast lines of division by no means hold good in this case.

The Permian strata were considered as forming a lower part of the New Red Sandstone, by Sedgwick: they were afterwards separated and called *Permian* by Murchison, from the ancient Government of Perm in Russia, where they are said to be extensively developed.

Between the neighbourhood of Nottingham and Tynemouth in Northumberland, the Magnesian Limestone is well developed, and at its base there is a laminated shaly limestone known as the Marl Slate. Both rocks are fossiliferous.

In many places the Magnesian Limestone consists of round masses, often as large as good-sized cannon-balls, all cemented together. These concretionary masses vary in diameter from an inch to about 2 feet, and they sometimes enclose organic remains. Mr. E. J. Garwood has maintained that the concretions are due to segregation, for he observes that planes of bedding pass through the concretions and their matrix. The concretions themselves contain a comparatively small amount of carbonate of magnesia, but in the matrix there is an amount not exceeding about 30 per cent. The concretions are due to the concentration of carbonate of lime, and this did not take place when the proportion of magnesia in the stratum was excessive, and when in consequence the distance between the particles of lime was very great. Fine sections of these beds are exposed in the sea-cliffs between Hartlepool and South Shields, especially at Marsden, where there are great outlying masses of rock rising out of the sands like ruined towers and castles, pierced by caverns with lofty ragged pillars and arches, worn out by the restless sea, and through which the daily tide flows.

In Nottinghamshire the relation of these Permian strata to the underlying Coal-measures, and the overlying Trias, or New Red series, is shown in the diagram on p. 119.

Looked on as a whole, the Magnesian Limestone of this district lies quite unconformably on the Carboniferous series, for while between Nottingham and the neighbourhood of Leeds the Permian Beds lie upon Coal-measures, between Leeds and the vicinity of Darlington they overlap the north edge of the Yorkshire coal-field, and rest directly on the Millstone Grit and associated shales as far as the south end of the Durham coal-field, north of which they again lie on Coal-measures.

In Leicestershire the double unconformity of Permian Beds on the Carboniferous rocks and of the Bunter Beds on the Permian has been shown by Mr. H. T. Brown. The Permian Beds consist of red and variegated marls, bands of breccia, and sandstone. The fragments in the breccia comprise Carboniferous and older Palæozoic rocks which must have been exposed not far off in Permian times; and Mr. Brown considers that the breccia was brought down by streams into the old Permian lake, and was, in fact, the rearranged talus and 'screes' derived from the subaerial waste of the old rocks.

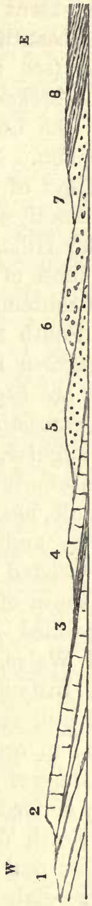


Fig. 40.—Section across Coal-measures, Permian, and New Red Strata, Nottinghamshire.

8. New Red Marl . . . } Keuper } Trias, or New Red Series.
7. White and Red Sandstones and Marls . . . } Bunter
6. Conglomerate or Pebble-beds
5. Red Sandstone
4. Magnesian Limestone . . . } Permian.
3. Red Marl . . .
2. Magnesian Limestone . . .
1. . . . Coal-measures.

In Lancashire, Cheshire, and North Staffordshire, the Permian strata chiefly consist of red marls and sandstones, interstratified near Manchester with a few thin bands of Magnesian Limestone. Similar marls and sandstones, bordered by New Red Sandstone, stretch at intervals from the border of the North Staffordshire coal-field to that of Shrewsbury, and skirt the Denbighshire coal-field on the east. In the more central parts of England the same kinds of rock border the Coalbrookdale, Forest of Wyre, South Staffordshire, and Warwickshire coal-fields.

In the Permian strata of Warwickshire there are beds of conglomerate, the waterworn pebbles of which largely consist of fragments of Carboniferous Limestone.

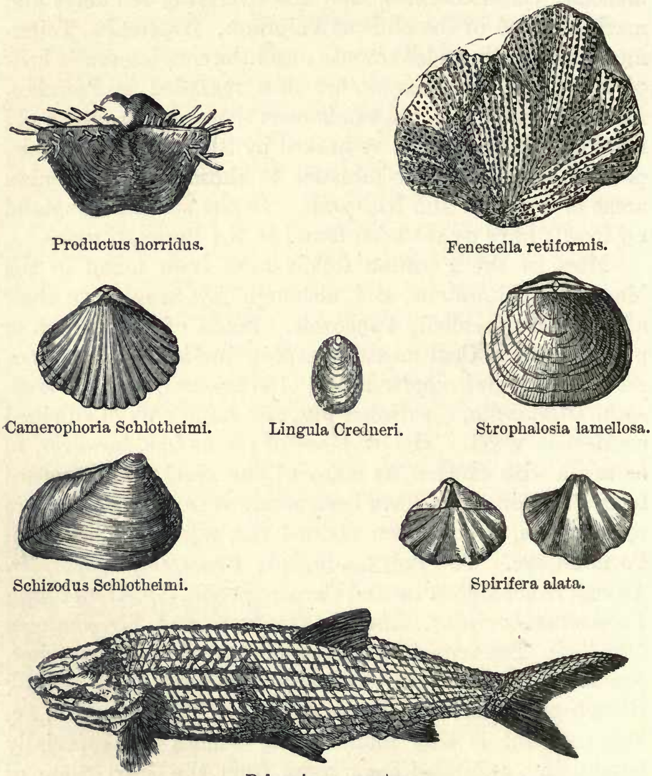
A large extent of Permian red sandstones and marls occupies the beautiful Vale of Eden in Westmoreland and Cumberland (see Fig. 129). Locally the curious term 'brockram' (broken rock) is applied to the breccias associated with the Lower Permian rocks near Appleby and Kirkby Stephen. Northwards the Permian strata extend into the valleys of the Nith and the Annan in Scotland, brecciated like those of the Vale of Eden, and of the Clent and Abberley Hills. The red sandstones of Dumfries are not unlike those of Penrith; but in the south of Scotland evidence of contemporaneous volcanic action is met with.

In the South Staffordshire district, and in the Clent and Bromsgrove Lickey Hills, the Permian marls and sandstones are capped by a remarkable brecciated conglomerate, consisting of pebbles and large blocks of stone, generally angular, imbedded in a marly paste. These conglomerate-beds are about 400 feet thick. South of Coalbrookdale, near Enville, and between that country and the Abberley and Malvern Hills, Permian rocks occur, largely associated with coarse brecciated conglomerates, similar to those of the Clent Hills. The fragments have mostly travelled from a distance, apparently from the borders of Wales, and some of them are three feet in diameter. Instances occur where the smooth surfaces of the stones still retain striations, not unlike in character those found in ordinary boulder-clay, or made by modern glaciers. Many of the stones are of greenstone and felstone, apparently derived from the eruptive rocks of Montgomeryshire and North Wales; and at the south end of the South Staffordshire coal-field, near Northfield, I found in these strata large slabs of *Pentamerus*-limestone, such as are only known in the Longmynd country, on the borders of the older rocks in Shropshire. So completely, indeed, does the whole deposit resemble a boulder-clay, that

I have no doubt there was a glacial episode during this epoch.

Far south in Devonshire the false-bedded red sandstones, breccias, conglomerates, and the overlying red clays and marls exposed in the cliffs at Paignton, Watcombe, Teignmouth, Dawlish, and Exmouth; and the conglomeratic beds of Heavitree, near Exeter, are now regarded as Permian. Associated with the red sandstones there are in places old lavas and tuffs that, as remarked by Sir Archibald Geikie, present the closest resemblance to those of the Permian areas of Ayrshire and Nithsdale. In the south of England no fossils have as yet been found in the Permian rocks.

Most of the Permian fossils have been found in the Magnesian Limestone, and, although few in number, their affinities are decidedly Palæozoic. Some of the genera of plants have a Coal-measure aspect, including *Calamites*, *Neuropteris*, *Sphenopteris*, and *Alethopteris*, besides *Walchia*, *Ullmannia*, *Cardicocarpus*, and fragments of silicified coniferous wood. The evidence of plants has, however, to be taken with caution, as many of the specimens recorded from Permian strata have been obtained from Coal-measure rocks which, having been stained red, were regarded as of Permian age. The Polyzoa include *Fenestella retiformis*. Among Brachiopoda we find *Camarophoria*, *Spirifera alata*, *Productus horridus*, *Lingula Credneri*, and *Strophalosia lamellosa*. The Lamellibranchs include *Bakewellia antiqua*, *Schizodus Schlotheimi*, and *Pleurophorus*; and among Gasteropods there are species of *Turbo*, *Pleurotomaria*, &c. *Temnocheilus* is also found. The Fishes are especially noteworthy, and most have come from the Marl Slate of Durham. They include *Palæoniscus comptus*, *Platysomus striatus*, *Cœlacanthus*, &c. All the Permian fishes have heterocercal tails, like the majority of the Palæozoic genera, in which the vertebral column is prolonged into the upper lobe of the tail, whereas in most of the modern fishes the vertebral column is not prolonged into either lobe. The saurian remains, both of the red rocks and of the Magnesian Limestone, are partly Amphibian, as shown by the Labyrinthodont *Dasyceps Bucklandi* of Kenilworth, the footprints in the red Permian sandstones of the Vale of



Palæoniscus comptus.

FIG. 41.—GROUP OF PERMIAN FOSSILS.

Eden, and Corncockle Moor, in Dumfriesshire, and by *Lepidotosaurus Duffi* of the lower part of the Magnesian Limestone; while others from the marl slate, *Protorosaurus Speneri* and *P. Huxleyi*, were true lizard-like Reptiles.

Excepting the Magnesian Limestone, all the Permian rocks are red. As with the thin pellicle of peroxide of iron that incrusts the grains of sand and mud of the Old Red Sandstone, so the colour of the red Permian sandstones and marls is due to a thin incrusting pellicle of peroxide of iron, such as I have elsewhere attempted to show is often characteristic of deposits in inland waters.

The evidence derived from the remains of Labyrinthodont Amphibia and of land Reptiles, clearly points to the close proximity of land. Many years ago numerous footprints were described by the late Sir William Jardine, which were found on the surfaces of beds of sandstone in Corncockle Moor and in other parts of Dumfriesshire. All of these footprints clearly indicate that the animals had walked on the wet sands, whose surfaces were afterwards dried by the heat of the sun, before the flooded waters overspread them with new layers of sediment. Pseudomorphs of crystals of salt in the Permian beds of the Vale of Eden, and deposits of gypsum and peroxide of iron, help to this conclusion, together with the occurrence of suncracks or rain-pittings impressed on the beds. The pseudomorphous crystals of salt tell of the evaporation of pools by solar heat, for neither crystals of chloride of sodium (salt), nor deposits of sulphate of lime (gypsum), could have been formed amid common mechanical sediments at the bottom of an open ocean.

If we now turn to the assemblage of Mollusca, we find it to be poor in number and dwarfed in aspect. The forms are more numerous in some places than in others, but wonderfully restricted when compared with the fauna of the Carboniferous Limestone. The Permian fossils may indeed be compared with the still less numerous fauna of the Caspian Sea, as far as that fauna is known; and that sea, or brackish lake, was, it is believed, once connected with the northern ocean, as the fauna seems to testify. My belief is, that these Permian waters were also of an inland, unhealthy nature, and, like those of the Caspian, had previously been connected with the open ocean. The chemical composition and lithological structure of the Magnesian Limestone, seem to me to afford strong hints that it was originally deposited in a large inland salt lake, under such circumstances that carbonates of lime and magnesia were deposited simultaneously, probably, by concentration of solutions due to evaporation.

Whether or not the water was too salt or too fresh for the healthy production of numerous shells and corals, is a question I have not attempted to solve, being content to prove (as I think) that the waters formed inland lakes, that lay in a large continent which began in Old Red Sandstone times, but had undergone many modifications in its physical geography before the Permian lake-basins came into existence.

CHAPTER XII.

TRIASSIC STRATA: NEW RED SANDSTONE AND MARL, AND RHÆTIC BEDS.

THE NEW RED SANDSTONE SERIES, or TRIAS, succeeds the Permian strata. It has received the name of *Trias* from the fact that when fully developed, as in Germany, it consists of the three great divisions of *Keuper*, *Muschelkalk*, and *Bunter*. In this country the Muschelkalk is probably represented, in point of time, by strata of a different sedimentary nature: in part by deposits grouped with our Bunter and Keuper. Comparatively few genera and no species of bivalve shells pass thus far upwards. The majority of the old genera of Brachiopoda disappear, and the whole grouping of the fossils now ceases to be Palæozoic, and assumes a character common to the Mesozoic or Secondary strata. The British Trias is as follows:—

Rhætic Beds.—White limestones, black shales, and marls.

Keuper:
- Red marls and thin bands of white sandstone, with gypsum and rock salt.
- Sandstones and marls (Waterstones), and conglomerates and breccias (Basement Beds).

Bunter:
- Soft red and mottled sandstone.
- Conglomerate and Pebble-beds.
- Soft red and mottled sandstone.

These beds, with variations, occupy the undulating lands from Sidmouth in Devonshire to West Somerset, along the banks of the Severn, and the eastern borders of the Palæozoic rocks of Herefordshire and North Wales.

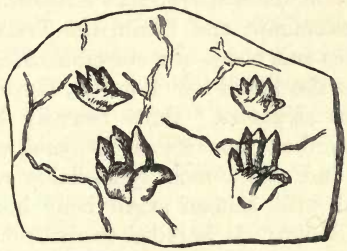
Thence they stretch far eastward to the Permian and Carboniferous rocks of Lancashire, North Staffordshire, and Derbyshire. They surround all the midland coal-fields and Permian beds between Shrewsbury, Coventry, and Derby, and thence, for the most part, unconformably overlying the Permian rocks, they stretch north in a long band from Nottingham to the river Tees. (See Figs. 42 and 40, p. 119.) In Cumberland, at St. Bees Head, the St. Bees Sandstone appears to represent the Bunter, and it rests on the Permian marls and thin bands of Magnesian Limestone and breccia. The same sandstone forms the fine rocky cliffs near Corby Castle, along the banks of the Eden. The Keuper sandstones and marls are represented at Kirklinton and Stanwix, near Carlisle.

Fig. 42.—Section across the New Red Series, Shropshire, showing its relation to the Permian Rocks and Coal-measures.

7. New Red Marl . . . . } Keuper.
6. White and red sandstones and conglomerate . . . } Keuper.
5. Red Sandstone
4. Conglomerate or Pebble-beds . . . } Bunter.
3. Red Sandstone
2. Red Sandstones and Marls . . . . } Permian.
1. . . . . Coal-measures.

No fossils are known in the New Red or Bunter Sandstone of England. The Bunter pebble-beds are well shown at Cannock Chase in Staffordshire, and they consist largely of liver-coloured quartzites, which have been derived partly from rocks like those of the Lickey Hills, or those of Hartshill. In Devonshire there are somewhat similar beds known as the Budleigh Salterton pebble-beds. The pebbles in both areas enclose fossils belonging to the rocks of which they are rolled fragments.

The *Lower Keuper Beds* consist of red, white, and brown sandstone, often ripple-marked, with interstratifications of red marl, and they contain bones and footprints (ichnites), chiefly of Labyrinthodonts, such as *Mastodonsaurus*, together with a few Plants and a peculiar Fish, *Dipteronotus cyphus*, found near Bromsgrove, in Worcestershire. The larger impressions of footprints are 8 to 10 inches in length, and in front of each there often is a smaller one made by the forefoot, Fig. 43. Remains of *Hyperodapedon* have been found in Warwickshire and again near Sidmouth in Devonshire. The *Upper Keuper*



Mastodonsaurus giganteus.

Estheria minuta.

FIG. 43.—TRIASSIC FOSSILS.

Beds consist mainly of red and variegated marls and clays, with occasional beds of sandstone. In the sandstones Labyrinthodont remains have been found, also Fishes; and lately Mr. R. B. Newton has described some Mollusca, apparently marine forms, that were found in the sandstone of Shrewley in Warwickshire.

Beds of Dolomitic (magnesian) conglomerate lie at the base of, and are intercalated with, the New Red Marl along the borders of the Mendip Hills. In equivalent beds at Clifton, near Bristol, the bones of *Thecodontosaurus* and *Palæosaurus* have been obtained.

The rock-salt of England lies chiefly in the great marly plains of Cheshire and Worcestershire: it occurs also in Durham. It is found at varying depths, in interrupted lenticular beds, ranging from a few feet to about 120 feet in thickness. The mass is usually of a reddish colour, due to the presence of ferruginous impurities; and it was doubtless precipitated in supersaturated salt lakes. This could only have been done by evaporation of the waters of lakes which had no outflow, like the Great Salt Lake of Utah, for example, or the salt lakes of Central Asia and of the Sahara.[1] The red marl varies from 500 to 2,000 feet in thickness, and contains a thin band of white sandstone, often with pseudomorphs of crystals of rock-salt, and also bearing a small bivalve Crustacean, *Estheria minuta*, and Fishes, *Semionotus* and *Hybodus Keuperi.*

In Scotland, at Lossiemouth and Elgin, the Triassic sandstones contain scutes and bones of a crocodile, *Stagonolepis Robertsoni*; also the lizard-like Reptiles, *Hyperodapedon* and *Telerpeton elginense.* Quite recently Mr. E. T. Newton has described remains of Dicynodonts, *Gordonia* and *Geikia*; and also a most remarkable reptilian skull, ornamented with sixteen small bony horns or spines, and named *Elginia.* It is allied to the South African *Pareiasaurus.* The age of the sandstones yielding these remains has been questioned by the Rev. George Gordon, because they rest with apparent conformity on the Old Red Sandstone, which yields *Holoptychius.* The Triassic character of the Reptiles is, however, a very strong indication that the 'reptiliferous sandstone' belongs to the New Red Series.

Evidence of Triassic sandstone and conglomerate has been met with at Raasay and near Broadford in Skye.

On the whole, the same kind of arguments already applied to the Permian strata, may, with increased force, be used in relation to the New Red Sandstone and marl, especially the occurrence of rock-salt, gypsum, the red colour of the rocks, and the prevalence of the footprints

[1] Ramsay 'On the Physical Relations of the New Red Marl, Rhætic Beds, and Lower Lias:' *Quart. Journ. Geol. Soc.*, vol. xxvii. p. 189.

and bones of Labyrinthodont Amphibia, and the remains of various Reptiles, and plants. Thus the New Red Sandstone was deposited in an inland lake, or lakes, possibly fresh, but probably brackish, and the overlying Keuper or New Red Marl was formed in a great salt lake, or lakes, if we take all Europe into account. But inferences still more striking may be drawn respecting the Physical Geography of the time.

By referring to the descriptions of the Old Red Sandstone, Carboniferous, Permian, and New Red formations, it will be seen that they all afford evidence of continental as opposed to purely marine conditions; in other words, a great continental epoch in Northern Europe (and in other regions), lasted from the close of the Upper Silurian epoch down to the end of the deposition of the New Red Marl, one main feature of which was the abundance of Reptilian and Amphibian life.

THE RHÆTIC BEDS occupy only a small space in England, estimated by superficial area; for in general they run in a mere narrow strip between the New Red Marl and the Lower Lias, and in fact form true beds of passage from the Marl to the Liassic strata.

On the north shore of the estuary of the Severn, at Penarth, near Cardiff, again at Watchet in Somerset, near Axmouth in Devon, and elsewhere in England, there is a perfect physical gradation between the New Red Marl and the Rhætic Beds, shown by interstratifications of red, green, and grey marls, which, varying in different areas, pass upward by degrees into black shales, with occasional sandy beds, and limestones. It is, therefore, impossible always to determine in this series precisely where the New Red Marl ends and the Rhætic Beds begin; and, indeed, all through the Red Marl, from bottom to top, there is a tendency to a recurrence of interstratified deposits that, lithologically, closely resemble the lower parts of the Rhætic beds. The lowest division comprises green and grey marls, closely united with the red and variegated Keuper Marls; above come black laminated shales; and higher up the 'White Lias' of Dorset and Somerset. At the base of the White Lias there occurs at Cotham, near Bristol, and in many parts of Somerset, the well-known landscape-marble, which exhibits arborescent markings, and these appear to have been formed during the solidification of the stone.

All over England, wherever the base of the Lower Lias is well seen, the Rhætic Beds, rarely more than 50, though occasionally as much as 100 feet thick, are found to lie between the Lias and the New Red Marl. Traces of the Beds have been found in the far north of Scotland, near Elgin, although there they have been broken up and incorporated with the Glacial Drift.

The Rhætic Beds seem to have been deposited in shallow seas and estuaries, or in lagoons or occasional salt lakes of small size, now and then separated from the sea by minor accidental changes in physical geography.

In the latter part of the Triassic epoch, as already stated, our Keuper Beds, or New Red Marls, were deposited in an area that now forms part of England, and this area was in those days a great salt lake.

Subsequently, during deposition of the marly sediments, by increase of rainfall, or climatic change of temperature, the water became somewhat less salt, but still sufficiently saline, by evaporation of the moisture on wet surfaces, to produce crystals of salt (now pseudomorphs) in sandy layers interstratified with the marls, together with layers and nodular masses of gypsum, which state of affairs continued up to, and even during, the deposition of recognised Rhætic strata. That Rhætic areas got dried by temporary exposure is certain, for besides the pseudomorphs, sun-cracks are common in the strata.

In our area, sinking of the district took place at or about the time when the lake or lakes got nearly filled with sediment, and a partial influx of the sea over shallow bottoms was the result. The deposits that ensued, accompanied by a small migration of marine forms of life, constitute the Rhætic Beds of England.

Many years ago, Edward Forbes stated to me that the fauna of the White Lias of Lyme Regis reminded him, in its assemblage of forms, of the molluscan fauna of the Caspian Sea, which is few in genera and species, and of an

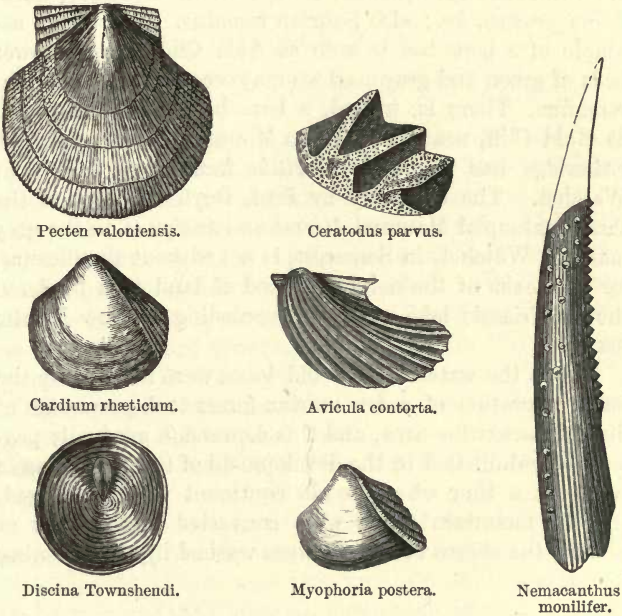


Fig. 44.—Group of Rhætic Fossils.

abnormal kind, in consequence of the brackish quality of the water.[1]

Among the commoner fossils we find in the White Lias *Cardium rhæticum, Monotis decussata, Myophoria postera,* and *Plicatula intusstriata*, together with *Ostrea liassica* and *Modiola minima,* which are prevalent in the basement-

[1] See *Life of E. Forbes*, by Wilson and Geikie, p. 418.

beds of the Lias. In the Black Shales below the White Lias, the characteristic fossil is *Avicula contorta*, and in the same beds we find *Pecten valoniensis* and *Discina Townshendi.* At and near the base of the shales there are one or two thin bone-beds, which contain bones, scales and teeth of Fishes, such as *Gyrolepis Alberti*, *Acrodus minimus*, *Saurichthys apicalis*, *Nemacanthus monilifer*, *Ceratodus parvus*, &c.; also Saurian remains. The finest example of a bone-bed is seen at Aust Cliff. In the lower beds of green and grey marl we may occasionally find Fish-remains. There is, indeed, a bone-bed in the green marl at Gold Cliff, near Newport, in Monmouthshire; and Mr. Etheridge has recorded *Gervillia* from these beds near Watchet. The discovery by Prof. Boyd Dawkins of the small marsupial Mammal *Microlestes antiquus*, in the grey marls at Watchet, in Somerset, is not without significance, for it speaks of the neighbourhood of land that bordered the old Triassic lake, and the succeeding shallow Rhætic sea.

When the waters of the old lakes were invaded by the sea, a migration of a few marine forms took possession of the old lacustrine area, and this depression gradually proceeding, culminated in the development of the great Liassic fauna, at a time when the old continent was submerged, and the mountain tracts were converted into groups of islands, the shores of which were washed by a broadening Liassic sea.

CHAPTER XIII.

JURASSIC OR LIASSIC AND OOLITIC STRATA.

In the previous chapter I stated that the continental area in which lay the lakes of the epoch of the New Red Marl, underwent partial submersion, during which our passage-beds, called the Rhætic strata, were deposited. This sinking of the land going on by degrees resulted in the formation of groups of islands, round which, first the Lias, and afterwards the Oolitic series were deposited, the whole, on the continent of Europe, and now often in Britain, being grouped under the name of *Jurassic* formations.

The general stratigraphical relations of the larger masses of the Liassic and Oolitic series, in the southern half of England, will be easily understood by reference to Fig. 7, p. 19.

The high ground now called Wales and Herefordshire formed part of an insular tract; Dartmoor and other elevations in Devon and Cornwall, the hilly regions of Derbyshire, and the Cumbrian mountains, may have formed other land areas; while parts of the south of Scotland, and the Highlands, also stood as islands washed by the Liassic Sea. It is not, however, to be supposed that the actual forms of these island territories were even approximately identical with those of the present mountains, and the limits and orographic contours of these fragments of an old physical geography can only be approximately guessed at. They have undoubtedly been subjected to repeated disturbance and upheaval since the beginning of the depo-

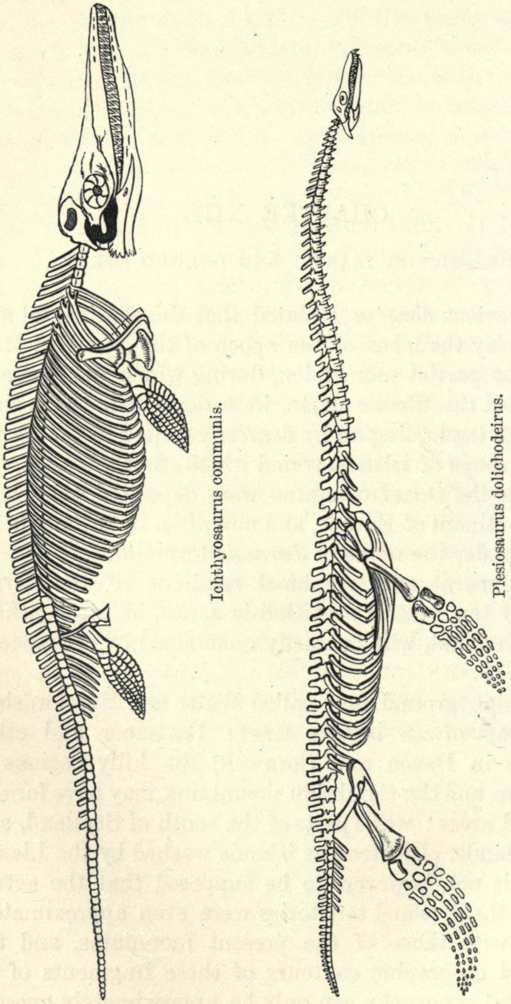


FIG. 45.—LOWER LIAS SAURIANS.

sition of the Lias, but after these old Palæozoic mountains were first upraised, they suffered so much from all the agents of waste and degradation, that in Liassic and pre-Liassic times no doubt they were higher than now, and occupied more extended areas.

The LOWER LIAS is between 900 and 1,000 feet thick, where best developed in England, and consists in the upper part of blue clay or shale (weathering brown), and in the lower part of blue argillaceous limestones, largely quarried in Leicestershire, Warwickshire, and elsewhere, for hydraulic lime. These limestones, lying flat and unconformably on the upturned and denuded edges of the Carboniferous Limestone, form splendid cliffs on the coast from Aberthaw to Dunraven in Glamorganshire, and, with the Rhætic beds, they are also well exposed in the coast sections at Watchet and Lyme Regis. From Dorset, interrupted only by the Mendip Hills, the Lower Lias strikes north and north-east, through the midland counties and Lincolnshire, to the sea-coast between Scarborough and Redcar, in Yorkshire. Throughout this area it usually forms a flat or undulating country, lying much in pasture land : the strata dipping gently to the east or south-east. Occasionally the limestones at the base of the Lower Lias form a low escarpment, generally facing west, and, almost invariably, the Middle Lias makes a similar and higher escarpment, the top of which is formed of a tough brown fossiliferous limestone, known as the Marlstone, from one to nearly thirty feet in thickness, and fairly constant in its occurrence from Dorsetshire to Yorkshire. The very indefinite base of the Middle Lias forms the eastern boundary of the outcrop of the Lower Lias.

Lower Lias is exposed by Dunrobin Castle in Sutherland, and it is again found in Mull, Skye, and Raasay. In Skye the beds are well shown on the foreshore at Broadford, where they were described by Sir A. Geikie. There we find bands largely made up of the Corals *Isastræa* and *Thecosmilia*. Again, the shales of Pabba, with

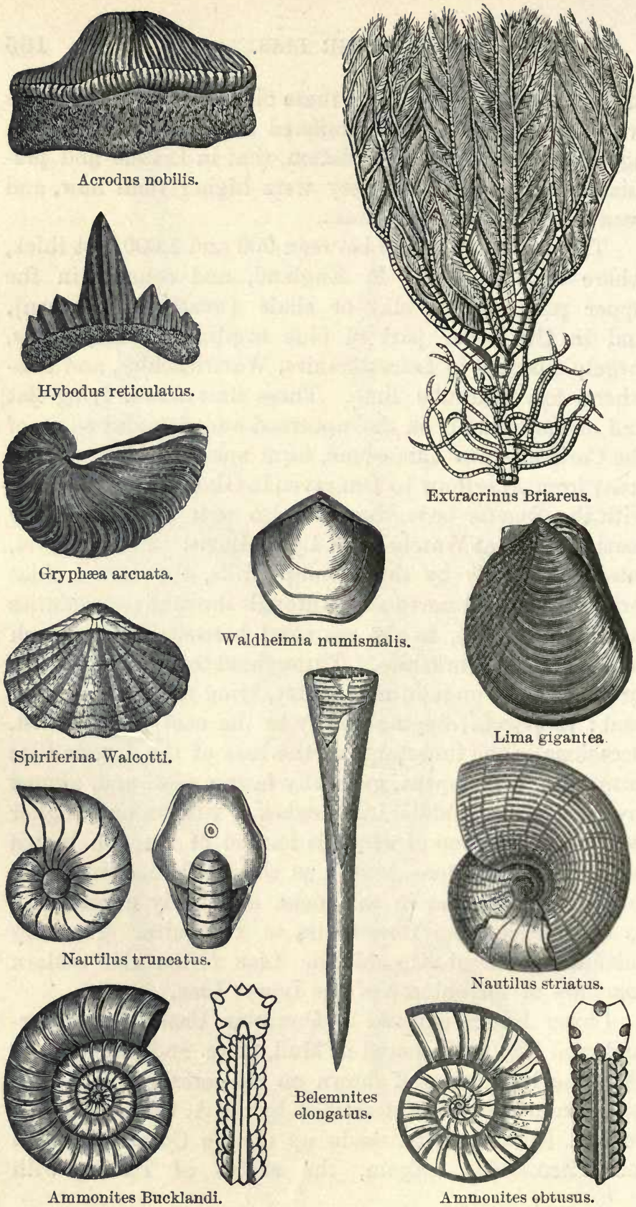


FIG. 46.—GROUP OF LOWER LIAS FOSSILS.

Ammonites Jamesoni, &c., are rich in fossils. The beds are traversed by numerous dykes of basalt.

The Lower Lias is rich in fossils. The strata yield *Extracrinus*, the 'Briarean Encrinite,' and *Pentacrinus basaltiformis*, among the Crinoids (Fig. 46); the Brachiopods, *Spiriferina Walcotti*, *Waldheimia numismalis*, and *Rhynchonella calcicosta*; and numbers of Lamellibranchs, such as *Gryphæa arcuata* or *incurva*, *Ostrea liassica*, *Lima gigantea*, *Avicula*, *Pholadomya*, *Hippopodium ponderosum*, *Cardinia*, and others. Of the Cephalopods, which are free swimmers, there are vast numbers. Among these are many Ammonites, the leading species of which are taken to indicate zones, or palæontological stages, which are characterised successively by different species, in ascending order, of *Ammonites planorbis*, *A. angulatus*, *A. Bucklandi*, *A. semicostatus*, *A. obtusus*, *A. oxynotus*, *A. armatus*, *A. Jamesoni*, and *A. capricornus*, &c. *Nautilus truncatus* and *N. striatus* also occur; and Belemnites are very abundant, especially in the shales, as at Golden Cap, near Lyme Regis. There are also many Fishes, such as *Hybodus*, *Acrodus*, *Dapedius*, &c. More striking are the great marine Saurians, the *Ichthyosaurus* (fish-lizard), the *Plesiosaurus*, and the flying reptile, or Pterodactyl *Dimorphodon*. Crustacea, such as *Eryon*, *Glyphea*, &c., are found in the limestones, near the base of the formation.

The Marlstone series, or Middle Lias, which succeeds the Lower Lias clay, is generally somewhat argillaceous below, graduating upward from the blue clays of the Lower Lias, through sandy shales, into a brown, ferruginous, soft, sandy rock, with hard nodular bands, and with its marked brown ferruginous limestone at the top. Fossils are poorly preserved in the shales, but they include *Ammonites margaritatus*, a species found also in the Marlstone or rock-bed above. In this bed there are many fossils, including *Ammonites spinatus*, *Belemnites*, *Pecten æquivalvis*, *Gryphæa cymbium*, *Modiola scalprum*, *Terebratula punctata*, and *Rhynchonella tetrahedra.* Gasteropods are fairly abundant. The Marlstone, which, in the form of sandy and ferruginous limestone, constitutes a good building-stone at Edge Hill in Warwickshire, yields in other places, as in the Cleveland district of Yorkshire and in some of the midland counties, a valuable

Ammonites margaritatus. Rhynchonella tetrahedra. Ammonites serpentinus.

FIG. 47.—MIDDLE LIAS. UPPER LIAS.

iron-ore. The Middle Lias occurs near Portree in Skye, and again in Raasay.

The UPPER LIAS CLAY plays a comparatively unimportant part in the physical geology of England. In Dorset and Somerset the beds are mainly represented by thin limestones and clays, which at Ilminster, Glastonbury Tor and other places have proved very fossiliferous. About Wotton-under-Edge the formation begins to get more definite, and from thence, in a narrow strip between the Marlstone rock, and the sands beneath the Inferior Oolite, it runs northward and round the northern borders of the Cotteswold Hills, by Dursley, Stroud, Painswick, and Chipping Campden, and following all the contours of the Oolitic escarpment, extends through the country from Chipping Norton to Banbury. In this progress, gradually increasing in thickness, it forms great tracts of clay land in Northamptonshire and in the neighbourhood of Uppingham and Oakham in Rutland; while further north, the clay runs in a long narrow strip, still overlying the Marlstone, into Yorkshire, where it is finally exposed in the sea-cliffs near Whitby, and where in old times great excavations were made for the extraction of shale, and the manufacture of alum.

Taken as a whole, the Upper Lias is a stiff dark blue clay or shale, with occasional layers of limestone often nodular. It is characterised by *Ammonites annulatus*, *A. serpentinus*, and *A. communis*, which in upward sequence mark zones. Among other species *A. bifrons* is conspicuous. Belemnites are abundant, *Nautilus* occurs, and among other fossils are *Inoceramus dubius* and *Leda ovum*. *Trigonia* is occasionally found; and this genus, so characteristic of the Oolites, occurs for the first time in the Middle Lias. Remains of Fishes, such as *Pachycormus* and *Leptolepis*, are found in the basement-beds of the Upper Lias. In Yorkshire, the well-known jet of Whitby is excavated from the shales in the cliffs, and is formed of the fossilised stems of coniferous trees that grew on the hilly islands, on the west and north. The Upper Lias is again met with in the Inner Hebrides.

The remarkable assemblage of large Reptilia that inhabited the Liassic seas, the number of Ammonites, Nautili, Belemnites, and other Mollusca, the swarms of Terebratulæ and Rhynchonellæ, all speak of warm seas, surrounding islands, on which grew Cycads and other plants, that seem to tell of a tropical or subtropical climate. This phase of the physical geography was continued into much later times.

In the basement-beds of both Lower and Upper Lias there are bands described by the Rev. P. B. Brodie as 'Insect-limestones.' These beds seem to indicate the proximity of land; but the Insect-remains have been taken to imply a temperate climate. They include Beetles, Grasshoppers, Dragon-flies, &c. Long ago Edward Forbes, working on the borders of the Ægean sea, observed that, during heavy rains, vast numbers of insects were washed into the sea, not such as inhabited its low hot shores, but those that lived in the high cool regions of the neighbouring mountains. These, caught in the floods of rain, were washed into rivers and borne onwards to the sea.

There was no break in time between the successive conventional divisions of the Lower, Middle, and Upper Lias. Each in ascending succession lies quite conformably on the other; between the Lower and Middle divisions there is a clear lithological passage, accompanied by a passage of species, and though there is generally a very sudden break in lithological character between the Marl-stone and the Upper Lias clay or shale (due, perhaps, to rapid depression of the area), yet a number of species are common to these divisions.

Few biologists and geologists now believe in the sudden extinction of entire old marine faunas, or even of the greater part of them, and their equally sudden replacement by new creations; for it begins to be generally understood that life is variable and progressive, the change of species in given areas being due chiefly, in comparatively short epochs, to migrations out of and into these areas, in consequence of changes of local conditions, such as depth of water, and nature of sediments, while in long periods of geological time, it is best accounted for by that process of evolution so clearly expounded by Darwin.

We now come to the OOLITIC SERIES of strata. On the flank of the Cotteswold escarpment, south of Wotton-under-Edge, in Gloucestershire, the Upper Lias clay is very poorly developed, and between it and the ordinary limestone of the Inferior Oolite, there are thick beds of soft brown sand, with intermittent hard, sandy, calcareous bands, containing occasional Ammonites, Belemnites, and bivalve shells. Above these there are bands of impure sandy and iron-shot limestone, called, by Dr. Wright, the Cephalopoda Bed, because of the prevalence in it of Ammonites and Belemnites, some of which, with other forms, are also common in the Upper Lias clay. This fact induced him to consider these sands and impure limestone to be so intimately related to the Upper Lias, that he named them 'the Upper Lias Sands' instead of the Sands of the Inferior Oolite, a name long before given to them by William Smith. Some of the fossils, however, are common to the overlying Oolitic formations, thus linking them in a continuous chain of specific life. Hence the strata form passage-beds between the Lias and Oolites; and John Phillips later on suggested the name Midford Sand for this intervening sandy formation, which is well developed from the cliffs of Bridport Harbour, by Yeovil and Midford near Bath, to the Cotteswold Hills. Generally speaking, the formation includes beds characterised by *Ammonites jurensis* and *A. opalinus*. *A. striatulus* is also a common form, as well as *Rhynchonella cynocephala*.

In the south of England the INFERIOR OOLITE first appears in the cliffs at Burton Bradstock, near Bridport Harbour in Dorset, whence, underlain by the before-mentioned sands, broken and interrupted by many faults, it ranges northward by Beaminster and Sherborne to the east end of the Mendip Hills and the neighbourhood of Bath, where it outcrops along the scarped hills intersected by so many winding valleys. Thence, in a long narrow strip, it runs on by Wotton-under-Edge, Dursley, and Painswick, in Gloucestershire, near which, on the flat-topped Cotteswold Hills east of Cheltenham, it broadens, and forms great part of the wide plateau that extends from Burford to the neighbourhood of Chipping Campden. Beyond this region, in Oxfordshire, a few miles north-east of Chipping Norton, it becomes mainly represented by sandy strata.

The Inferior Oolite consists chiefly of yellow limestone, and along with other limestones of the series is called oolitic, for in many cases the beds consist of concretionary bodies about the size of a pin's head, compacted like the eggs that form the roe of a fish (egg-stone) and cemented in a calcareous matrix. One of the most typical sections occurs near Cheltenham, on the summit of the bold escarpment that overlooks that town. At the base there is a rock, locally called pea-grit, which consists of pea or bean-shaped concretions. The calcareous matter that produced these, seems to have been plastered round nuclei, more or less mechanically, as suggested by E. Witchell. In the overlying freestones the oolitic grains show a concentric and radiate structure, indicating that the carbonate of lime has been deposited from solution around nuclei. It is thought that the deposition of calcareous matter may have been influenced by the presence of organisms such as calcareous Algæ; and Mr. E. Wethered has found abundant evidence of a minute tubular structure which he identifies as *Girvanella*.

The pea-grit is itself fossiliferous, and above the freestones are other fossil-beds, known as the Gryphite Grit, from the prevalence of *Gryphæa sublobata*, the Trigonia Grit, and the Clypeus Grit. These are beds of sandy and oolitic limestone to which strictly the term *Grit* is inapplicable. In Dorsetshire, and also at Dundry, in Somerset, Ammonites are most plentiful in the Inferior Oolite, and they include, in upward sequence, *Ammonites Murchisonæ*, *A. humphriesianus*, and *A. Parkinsoni*, which are taken to indicate zones. Several species of *Nautilus* are found. The fossils include the Gasteropods *Nerinæa*, *Amberleya*, and *Pleurotomaria*; and many Lamellibranchs, such as *Pholadomya fidicula*, *Ceromya*, *Astarte*, *Trigonia*, &c. Brachiopods form rich fossil-beds in places and include *Terebratula perovalis*, *T. sphæroidalis*, *T. globata*, *T. fimbria*, and *Rhynchonella spinosa*. Among Sea-urchins, *Clypeus Ploti*, *Pseudodiadema*, and *Pygaster* may be found; also many Corals and Polyzoa.

Passing from Gloucestershire into Oxfordshire, as already noted, the Inferior Oolite becomes more sandy, the limestone disappears by degrees, and for a space from near Banbury to Northampton, we have only a sandy and ferruginous division, locally known as the Northampton Sands. By-and-by, in the district of Rockingham near Geddington, the Inferior Oolite Limestone begins to reappear, overlying the Northampton Sands, and, thickening by degrees, it forms the surface of a great tract of country towards Stamford, Ketton, Barnack, Grantham, Ancaster, and Lincoln. The Inferior Oolite of this district is known as the Lincolnshire Limestone, and yields many famous building-stones. Slaty beds occasionally occur at its base, and from their being worked at

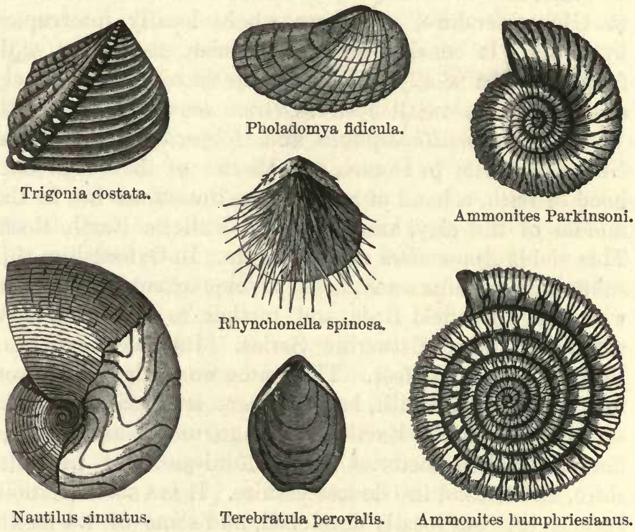


FIG. 48.—GROUP OF INFERIOR OOLITE FOSSILS.

Collyweston, near Stamford, they are known as Collyweston Slate. Like the similar beds at Stonesfield, they are flaggy limestones, and yield stone-tiles, and not true slates. The ironstone in the Northampton Sands has been largely worked in Northamptonshire, while above it the sands, often white, contain rootlets of plants, with seams of lignite, miniature underclays, and thin seams containing *Cyrena* (a fresh-water bivalve shell). These sandy beds have been distinguished by Prof. Judd as the *Lower*

Estuarine Series; and they underlie the Lincolnshire Limestone, where present.

Plants are rare in the purely marine strata of Gloucestershire and the south of England, but fragments of coniferous trees are sometimes found, the most remarkable of which is a large cone of *Araucarites*.

The Fuller's Earth or Fullonian Formation accompanies and overlies the Inferior Oolite from Dorset to Gloucestershire, excepting where locally interrupted by faults. It consists chiefly of bluish marly clay, with frequent thin shelly bands of limestone, often largely charged with a small oyster, *Ostrea acuminata*, and with *Waldheimia ornithocephala* and *Rhynchonella varians*. Near Sherborne in Dorset, and thence to the neighbourhood of Bath, a band of argillaceous limestones lies in the middle of the clay, known as the Fuller's Earth Rock. This yields *Ammonites subcontractus*. In Oxfordshire this subformation thins away, being to some extent incorporated with the Stonesfield Beds, and, further to the north-east, with the Upper Estuarine Series. Its thickness, near Bath, is about 150 feet. The name was originally given to it by William Smith, because there it contains beds of economic Fuller's Earth, long ago much used in the famous woollen factories of Bradford-on-Avon in Wiltshire, and Stroud in Gloucestershire. It is a subformation, because it is but locally developed, and some of its fossils are also common in the Inferior Oolite, though a larger number are met with in the Great Oolite.

The *Upper Estuarine Series*, which is developed in Northamptonshire and Lincolnshire, occurs between the Inferior and Great Oolite, and consists of coloured clays and sands that yield marine and fresh-water shells, and contain vertical plant-markings, like the Lower Estuarine Series. They are about 25 feet thick.

The Great Oolite succeeds the Fuller's Earth, and consists, where fully developed, of Stonesfield Slate, at the base, succeeded by Great or Bath Oolite, and Forest Marble.

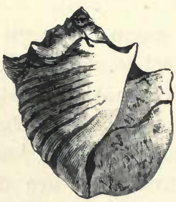
The local development called the *Stonesfield Slate* consists of beds of laminated shelly and oolitic limestone and sandy flags, a few feet thick, and containing Ferns, *Glossopteris*, *Pecopteris*, &c.; Cycads, *Clathraria Bucklandi* and *Ptilophlyllum*, and Coniferæ. Elytra of Beetles and wings of other Insects (*Libellula Westwoodi*, &c.); also, among Mollusca, *Ostrea*, *Lima*, *Pecten*, *Trigonia impressa*, and other shells, are all found in these thin shallow-water deposits. Remains of numerous Fishes are met with. The Reptiles include Crocodiles of the genus *Teleosaurus*, scutes of Chelonians, together with a great carnivorous Dinosaur, *Megalosaurus Bucklandi*, that walked on the neighbouring land, and was probably about 30 feet in length. A flying Reptile, *Rhamphocephalus Bucklandi*, allied to the Pterodactyl, is found in this subformation, which has long been especially celebrated as containing the remains of Mammals. These include species of small insectivorous marsupials, *Amphitherium*, *Phascolotherium*, and also *Stereognathus*.

The Stonesfield Slate is by no means of universal occurrence at the base of the Great Oolite, and is chiefly known in those parts of Gloucestershire that lie eastward of Cheltenham on the broad Oolitic plateau, and in Oxfordshire at the village of Stonesfield, where it is best known. There it is largely manufactured into what are called 'slates,' but are in reality stone-tiles—the coarse fissile character of which has no relation to what is known as slaty cleavage. From these areas going south along the Oolites, the Stonesfield Slate rapidly thins away, or changes its lithological character, for it is but occasionally seen at the base of the Great Oolite towards Wotton-under-Edge and Bath. In the opposite direction, going northward, the Stonesfield Slate dies away, and is perhaps overlapped by higher members of the Great Oolite.

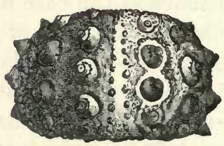
The Great Oolite was originally so called by William Smith, to distinguish it from the Inferior Oolite, which lies below the Fuller's Earth. It is often named the Bath

Oolite, because the greatest development of that excellent building-stone is near the city, which is almost entirely built of 'Bath stone.' The best beds of the Great Oolite are of cream-coloured oolitic limestone, so soft when first extracted from the quarry that it can be easily sawed into blocks, but it hardens on exposure. In Dorsetshire there is no evidence of this formation, and its absence appears to be due to the overlap, attended by contemporaneous erosion, of the Forest Marble. It first makes its appearance near Norton St. Philip, about six miles south of Bath, whence, overlaid by the Forest Marble, it ranges northerly, forming the flat-topped scarped hills on either side of the Avon near Bath, and so on to Minchinhampton. Beyond this it forms a large part of the table lands, intersected by valleys, that lie between Minchinhampton in Gloucestershire and Towcester in Northamptonshire.

Corals occur in the Great Oolite, chiefly belonging to the genera *Calamophyllia*, *Isastræa*, &c.; also Brachiopods,



Purpuroidea Morrisea.



Acrosalenia hemicidaroides.

FIG. 49.—GREAT OOLITE FOSSILS.

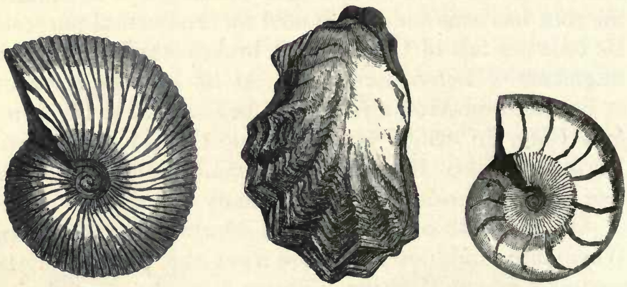
such as *Rhynchonella concinna* and *Terebratula maxillata*. Great numbers of Lamellibranchs are found, including *Ostrea Sowerbyi*, *Pecten vagans*, *Lima cardiiformis*, *Astarte*, *Ceromya concentrica*, *Pholadomya socialis*, *Cyprina loweana*, and many others. Near Minchinhampton, the Great Oolite, chiefly owing to the labours of Lycett, has proved to be rich in Gasteropods, among the most common of which are *Patella*, *Pleurotomaria*, *Trochotoma*, *Purpuroidea Morrisea*, *Natica*, *Nerinæa*, *Alaria*, *Ceritella*, *Cylindrites*, *Turbo*, and many others. Ammonites and Belemnites are rare. Echinodermata of the genera *Acrosalenia*, *Echinobrissus*, and others are not uncommon. Fishes' teeth, *Hybodus*, *Mesodon*, and *Strophodus*, and Reptiles of the genera *Teleosaurus* and *Megalosaurus* are found, also the gigantic *Cetiosaurus* (or whale-lizard), probably about 50 feet in length, and most likely amphibious.

The *Forest Marble* forms the topmost beds of the strata that usually are called Great Oolite. It includes beds of clay and shale, with many layers of shelly and oolitic limestone, with much false bedding, and as a marble the rock has sometimes been used for ornamental purposes. Its beds are full of Oysters and broken shells of *Pecten*, fragments of Echinoderms, &c. At its base there occurs at Bradford-on-Avon a rich fossil-bed known as the *Bradford Clay*, in which is found the Crinoid, *Apiocrinus Parkinsoni*, also *Waldheimia digona*, *Terebratula coarctata*, *Rhynchonella varians*, and many Polyzoa.

On the south coast the Forest Marble is exposed near Weymouth, and here and there along the coast to Eype, west of Bridport Harbour. Thence it ranges by Wincanton to Frome in Somersetshire. Throughout this area it rests directly on the Fuller's Earth formation. At Bath it overlies the Great Oolite, and forms the surface of tracts of country at Badminton, Malmesbury, Cirencester, and Burford, in Gloucestershire; it extends from Witney, by Woodstock, to the neighbourhood of Buckingham, beyond which its place is taken by the *Great Oolite Clay*, of Northamptonshire and Lincolnshire. This clay comprises green, red, purple, and other clays and sandy beds, and is not unlike the Upper Estuarine Series; it contains *Ostrea subrugulosa*, but has yielded no fresh-water Mollusca.

The Cornbrash forms the uppermost member of those formations that are usually classed as Lower Oolite. It is generally of inconsiderable thickness (15 or 25 feet), and, beginning in Dorset between Bridport and Weymouth, it ranges across that county, excepting where overlapped by the Cretaceous strata between Abbotsbury and the neighbourhood of Evershot. It is remarkably constant all through Wiltshire, Gloucestershire, Oxfordshire, Bedfordshire, and Northamptonshire, and onward into Lincolnshire; but north of the Humber it disappears for a space, being again overlapped by unconformable Cretaceous strata.

Throughout this long range it maintains the same general lithological character. It is mainly formed of pale marly limestones and marls, passing in places into shelly



Ammonites macrocephalus. Ostrea flabelloides. Ammonites discus.

FIG. 50.—CORNBRASH FOSSILS.

building-stones. When partly decomposed near the surface, it assumes a rubbly character, and forms a fertile soil, whence its agricultural name of Cornbrash, the word *brash* being an old word expressive of this loose rubbly character.

The Cornbrash is generally very fossiliferous, the assemblage of Lamellibranchs being much the same as in the Great and Inferior Oolites. They include *Pecten vagans*, *Ostrea flabelloides*, *Avicula echinata*, *Pholadomya*, *Myacites*, &c.

Among the Cephalopods *Ammonites macrocephalus* is characteristic. *A. discus* is also found. Brachiopods are abundant, and they include *Waldheimia obovata*, *Terebra-*

tula intermedia, &c. The Sea-urchin *Echinobrissus clunicularis* is abundant.

In considering the Oolitic Series we find that the division of these strata into *formations* is in great part lithological, and the difference of faunas in them was dependent on changes of conditions of depth, &c., in a sea where limestone, sands, or clays were being deposited. Although different stages, as in the Lias, are characterised by various species of Ammonites, and other forms of life exhibit specific changes in successive strata, yet it is not to be implied that these palæontological divisions consist of perfectly distinct zones, each having its own species, which have little connection with each other. Many species of fossils range upwards from the Inferior Oolite to the Cornbrash; others, like the Ammonites, exhibit more rapid changes, so that their species are restricted within narrower limits in point of time. Having, however, often a wide range in space, they serve to mark approximate periods of time.

The occurrence of Estuarine Beds in the Lower Oolites of the midland counties is full of interest. When we think of the meaning of these phenomena, it is evident that, while from Gloucestershire to the south coast, all the equivalent strata are marine, in Northamptonshire, Rutland, and Lincolnshire, a somewhat different set of conditions prevailed. It may be inferred that temporary elevation of the old marine deposits, in places, quite above the level of the sea, formed swampy terrestrial surfaces, through which wandered minor streams inhabited by freshwater shells. Further north this fact becomes still more plain.

After crossing the Humber, and passing the unconformable overlap of the Cretaceous rocks of the Yorkshire Wolds, a series of Oolitic strata appears in the North Riding, forming a great tract of beautiful hilly country, the sections of which are best seen in the coast cliffs between Filey and Whitby. The lithological characters, and mode of formation, of all the strata that are presumed to lie between the horizon of the base of the Inferior Oolite and the Cornbrash, are very different from those of the strata in the south of England.

Above the Upper Lias shales comes the Dogger Series, containing marine fossils and representing in part the Midford and Northampton Sands. Higher up there is a great series of Estuarine Beds, divided into Lower, Middle, and Upper, and representing the strata from the Inferior Oolite to the base of the Cornbrash. In this great series there are marine bands, known as the Millepore Bed and the Scarborough Limestone, which contain fossils of the Inferior Oolite; but the mass of the formation comprises shales and sandstones, with few organic remains except those of plants. What is of especial interest is that there are distinct bands of coal, interstratified chiefly with the shales, and other seams of carbonaceous matter more interrupted and broken. Moreover, the coal-beds have not been formed of drifted vegetation, for underneath each bed there occurs an *underclay* or old soil, charged with the roots of those plants, the decay of which on the spot formed the thin beds of coal, just in the manner that coal-beds were formed during the Coal-measure epoch, but, in the case of these Oolitic coal-beds, on a much smaller scale. Curiously enough, not only in Yorkshire, but far away at Brora, in Sutherlandshire, the Lower Oolites contain layers of coal, and there the principal band, between 3 and 4 feet thick, is worked like an ordinary coal-mine. Cropping out on the foreshore, it was first dug by the fishermen on the beach, and has since been followed underground. Similar beds with a coal-seam occur on the foreshore below the high cliffs north of Cromarty.

The succeeding formations, classed as the Middle Oolites, consist of the following divisions, the older being the Oxford Clay :—

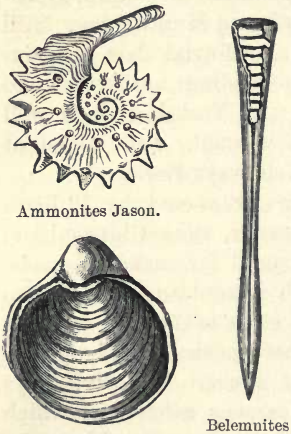
Corallian .	Coral Rag. Coralline Oolite. Calcareous Grit.	Oxford Clay	Clay. Kellaways Rock. Clay ; a thin band.

In the south of England the OXFORD CLAY occupies considerable strips of country near Weymouth, and is 500 or 600 feet thick. It is well shown in the cliffs between Weymouth and Osmington, and again on the borders of Radipole Lake and of the Fleet. Further north it occupies the vale of Blackmore, and extends in a broad tract of country, by Melksham and Chippenham, to Oxford, Buckingham, Fenny Stratford, Bedford, and Huntingdon. Still further north it underlies the great alluvial flats of Cambridgeshire and Lincolnshire, extending northwards to Brigg and the Humber shore. In Yorkshire it is well exposed in the cliffs near Scarborough, and inland at Hackness, accompanied by the Kellaways Rock.

The Kellaways Rock was first observed by William Smith, at the village of Kellaways, near Chippenham, where the fossiliferous rock was used for mending roads. The thin clay that lies beneath it contains species also found in the Cornbrash, and the same is the case with the Kellaways Rock; but many other species range up into the main mass of Oxford Clay above. The Kellaways Rock consists of sands and calcareous sandstone, which sometimes appear as large concretionary masses, or 'doggers.' Among its fossils we find *Ammonites calloviensis*, *A. modiolaris*, *Gryphæa bilobata*, *Myacites recurvus*, &c.

The Kellaways Beds form the basement-beds of the Oxford Clay. They have not been observed in their prominent lithological character at Weymouth; but in most other parts of the country, wherever sections have been opened up they have been seen—near Cirencester, Bedford, and through Lincolnshire and Yorkshire. In Sutherlandshire, as observed by Professor Judd, the Kellaways Rock forms a roof-bed above the coal worked in the Lower Oolite at Brora, and the higher beds of shale are well shown in the banks of the river near the coal-mine. Beds of like nature occur on the foreshore north-east of Cromarty. Among the Western Isles the Oxford Clay is exposed at Uig, and at the Quiraing by Loch Staffin in Skye, as pointed out by Edward Forbes, where it occurs beneath the Tertiary basalt. Again it is seen in the Isle of Eigg.

The Oxford Clay is especially characterised, in ascending order, by *Ammonites Jason*, *A. Lamberti*, and *A. cordatus*. Among other fossils the large *Belemnites Oweni* is conspicuous, also *B. hastatus*. *Gryphæa dilatata* is abundant in the upper beds, and among other fossils we find *Modiola bipartita*, *Nucula nuda*, *Serpula vertebralis*, and remains of Fishes and Saurians.



Ammonites Jason. Gryphæa dilatata. Belemnites hastatus.

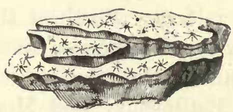
FIG. 51.—OXFORD CLAY FOSSILS.

The CORALLIAN BEDS comprise a series of grits and clays (Lower Calcareous Grit), surmounted by fine oolites, shelly limestones, and bands of coral-rock (Coral Rag). The formation is well shown in the cliffs south of Weymouth, and again at Osmington, where the foreshores in places are paved with *Trigonia*-beds, yielding *Trigonia clavellata*, &c. North of this neighbourhood the beds are found at Sturminster Newton, Calne, Faringdon, Abingdon, and Oxford. To the north-east there is a representative of the Oolite at Upware, near Cambridge, but elsewhere in its extent through Bedfordshire and Lincolnshire the formation is mainly represented by clay (Ampthill Clay). In Yorkshire the rock-beds are well developed at Filey Brigg, at Malton, and elsewhere. Again, at the famous Clyne quarry, at Brora in Sutherland, sandstones of Corallian age are worked, and these yield *Ammonites perarmatus* and other fossils, including many Cycad remains.

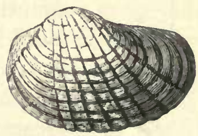
The characteristic Ammonites are *A. perarmatus*, in the lower beds, and *A. plicatilis* in the upper. Among other fossils we find *Belemnites abbreviatus*, *Nerinæa*, *Chemnitzia heddingtonensis*, the large *Bourguetia* (*Phasianella*) *striata*, *Pholadomya æqualis*, *Gervillia*, *Pinna*, &c. Among Sea-urchins, *Hemicidaris intermedia* and *Echinobrissus scutatus* are characteristic, while spines of *Cidaris florigemma* are abundant at certain horizons. In the upper beds Corals are plentiful, and many have been obtained at Steeple Ashton in Wiltshire; they include *Isastræa explanata*, *Thecosmilia*, *Thamnastræa*, &c. Oolitic

Cidaris florigemma.

Chemnitzia heddingtonensis.



Isastræa explanata.



Pholadomya æqualis.

FIG. 52.—GROUP OF CORALLIAN FOSSILS.

iron-ore occurs in the upper part of the formation at Westbury in Wiltshire, and Abbotsbury in Dorset.

This formation is rarely more than about 300 feet thick, and is intimately connected with the Oxford Clay below, and with the Kimeridge Clay above.[1]

For reasons connected with the physical geography of this epoch, which will be mentioned further on, I confine the Upper Oolite to two formations—the Kimeridge Clay, and Portland Beds.

[1] See memoir, 'On the Corallian Rocks of England,' by J. F. Blake and W. H. Hudleston, *Quart. Journ. Geol. Soc.*, vol. xxxiii. p. 260.

Fig. 53.—Section of the Oolitic and Purbeck Strata, Isle of Portland.

1. Kimeridge Clay. 2. Portland Sand. 3. Portland Limestone. 4. Purbeck Beds.

The stratigraphical arrangement of these strata and of the overlying Purbeck Beds is well seen in the Isle of Portland, where all the strata dip gently from north to south, as shown in the annexed diagram.

The Kimeridge Clay takes its name from Kimeridge Bay in Dorset, in the cliffs of which its dark shales are well exposed, with bands of cement-stones and many fossils. Certain hard, shaly bands at Little Kimeridge have at intervals been used for the manufacture of naphtha and mineral oils, but never with great success; one layer in particular is known as 'Kimeridge Coal,' and this has been burnt as fuel by the cottagers. West of this area the clay is well known in the northern half of Portland Isle, in Portland Road, and in the country near the Chalk hills, between Ringstead Bay and Abbotsbury. North of this it is overlapped by the Cretaceous rocks, but it reappears along the foot of the escarpment below Shaftesbury and Mere, again near Devizes, and Calne, whence it comes on in great force, covering a broad tract of country by Swindon, and eastward to Abingdon. Further on it extends by Headington, near Oxford, to near Aylesbury, Quainton, and Stewkley; but near Leighton Buzzard it is overlapped by broad-spreading strata of Lower Greensand. Between this area and Lincolnshire it is exposed here and there, as in the Isle of Ely, and again near Downham Market, in Norfolk. It underlies part of the Fenland, and trends north in a strip at the base of the Lincolnshire Wolds as far as the

Humber, where it is again unconformably overlapped by the Cretaceous strata of the Yorkshire Wolds, to reappear in the Vale of Pickering, between the Hambleton Hills and Filey Bay in Yorkshire. The Kimeridge Clay is in places from 500 to 1,200 feet in thickness, the full amount being penetrated in the Sub-wealden Boring near Battle, beneath the Purbeck and Portland Beds.

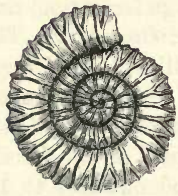
In Scotland dark shales, with many fossils of the Kimeridge formation, occur on the foreshore near Eathie, south of Cromarty. They early attracted the attention of Hugh Miller, who, regarding the strata as 'Lias,' gave graphic accounts of them, and obtained some interesting plant-remains—Conifers, Cycads, and Ferns. Similar beds are exposed on the foreshore and in the banks of burns at Loth and onwards to Helmsdale in Sutherlandshire. A great fault, nearly twenty miles in length, runs along the shore, and throws the Secondary strata down against the older Palæozoic rocks on the north-west. Interstratified with the black shales near Helmsdale, there are occasional beds of brecciated conglomerate. The shales contain thin layers of plants and many broken shells, and the breccias contain angular and subangular blocks, chiefly of Old Red Sandstone, with a mixture of the older rocks of the Highlands, sometimes 6 or 8 feet in diameter, in fact, boulder-beds, which long ago suggested to me the action of floating ice. Professor Judd remarks that angular masses, just separated from their parent rock by frosts or landslips, have been mingled with subangular fragments and pebbles formed along river-beds, and all have been commingled with trunks of trees, stems of cycads, &c., and interstratified with the marine muds.[1] The Portlandian Coral, *Isastræa oblonga*, occurs abundantly in the higher strata near Navidale. These beds are penetrated by some curious sandstone dykes to which attention was called by Strickland, who

[1] See his memoirs on 'The Secondary Rocks of Scotland,' *Quart. Journ. Geol. Soc.*, vol. xxix. p. 97, vol. xxx. p. 220, and vol. xxxiv. p. 660.

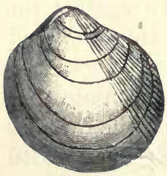
considered that old fissures were filled up by aqueous deposition of sand.

Peculiarly characteristic of the Kimeridge Clay is the oyster, *Ostrea deltoidea*, also *Exogyra virgula*, *Cardium striatulum*, *Lucina minuscula*, *Rhynchonella inconstans*, and *Lingula ovalis*. Among Cephalopods we find *Ammonites alternans*, *A. mutabilis*, *A. biplex*, and a number

Ostrea deltoidea.



Ammonites biplex.



Cardium striatulum.

Exogyra virgula.

Rhynchonella inconstans.

FIG. 54.—GROUP OF KIMERIDGE CLAY FOSSILS.

of Belemnites. Fishes are found, and many remains of Reptiles.

The PORTLAND LIMESTONE and SAND lie above the Kimeridge Clay. The best sections of these rocks occur in the Isle of Portland, as shown in Fig. 53, p. 154, and further east along the 'iron-bound' coast at Gad Cliff, St. Aldhelm's Head, and onwards to Durlston Head. The sand which forms the base of the formation is there 150 feet thick, and the limestone about 70. The lower part of the Portland Limestone in Dorset consists of cherty limestones; the upper part comprises the valuable freestones known as Portland Stone, and used in many public buildings, of which St. Paul's Cathedral may be cited as an example. The limestone, like those of most other Oolite formations, is cream-coloured, and some layers are very fossiliferous. Among the most common forms found in it are *Trigonia gibbosa* and *T. incurva*, *Pecten lamellosus*, *Ostrea expansa*, *Cardium dissimile*, *Lucina portlandica*,

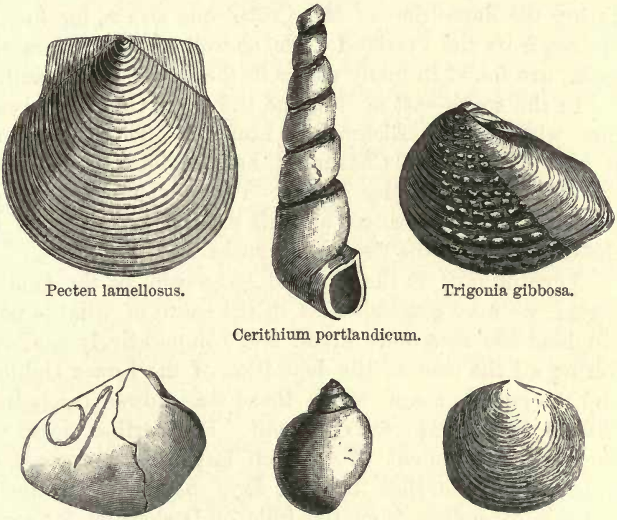


Fig. 55.—Group of Portlandian Fossils.

Cerithium portlandicum, *Natica elegans*, and the large Ammonites known as *Ammonites giganteus*. The Portland stone contains some beds of a very chalky nature, as at Upwey, near Weymouth, and in the Vale of Wardour; indeed, its characters vary very much. The principal building-stones have been quarried between St. Aldhelm's Head and Tilly Whim, by Durlston Head, where they consist of oolitic limestones, like those of Portland. In the Vale of Wardour the freestone is a very sandy limestone, while at Swindon the stone-beds are represented mainly by sand with irregular masses of hard calcareous sandstone (Swindon Stone). Near Tisbury, in the Vale of Wardour, the cherty layers yield a Coral, *Isastræa oblonga.* Portland Beds are seen at intervals from Swindon by Thame to Aylesbury, but further north they are not recognised except in certain clay-beds at Speeton in Yorkshire. The strata have evidently been exposed to denudation before and during the deposition of the Cretaceous strata, for fossils derived from the Portland Beds, as well as other Jurassic rocks, are found in many places in the Lower Greensand.

In the south-east of England the Great Oolite has been met with under Richmond, London, and Streatham; Oxford Clay under Chatham; and higher members of the Oolitic Series under Dover. There is thus evidence of considerable disturbance, as well as denudation, prior to the deposition of the Cretaceous rocks.

Turning now to the physical geography of the Oolitic period, we may conclude that in the south of what is now England the seas were broad and comparatively shallow, during all the time of the deposition of the Lower Oolites, and the islands round which these seas flowed (including Wales) were comparatively small. But further north we come to a fragment of a much larger land, formed of Palæozoic rocks, that in those days made a mountainous country extending from the hills of Derbyshire far away to the northern extremity of Scotland, and how much further entire, or broken into islands, no man yet knows. In spite of disturbances of upheaval of later date than these Oolitic times, it may also very well have been that this old land was much higher than the highest Highland mountains of the present day, seeing the vast amount of waste and degradation that they have undergone since that ancient time, and we may be sure that it was encompassed by seas of this lower Mesozoic epoch, for fragments of the Oolitic strata still surround the island. This was the larger land, from which the rivers flowed that deposited the fresh-water and estuarine beds previously described.

On the low banks of these rivers grew many a plant now represented merely by indistinct impressions—

> 'Their meaning lost,
> Save what remains on stone, or fragments vast'—

in which the relics of species of Cycads and Conifers and other forms, together with *Equisetum*, which grew in the still waters on their borders, while Marsupial mammals on the shores, and *Trigonia* and many Brachiopods in the seas, help us to realise that the physical characteristics of the time in some degree resembled those of Australia in our own day, a circumstance first noticed by Owen.

This state of affairs was at length partly brought to an end by a gradual submergence, during which the Oxford and Kimeridge Clays were deposited in open seas, but the sinking of the area was not by any means so great as to swallow up the old islands round which the strata were formed, and which still last, much changed, as the most lofty portions of Great Britain. Such fragments of the Jurassic strata as still remain on the coasts of Scotland throw some light on this question.

Such is a brief outline of the Oolitic strata of this country. It will be observed that in this description I have specially insisted on the unconformable overlapping of the Cretaceous strata across the Portland, Kimeridge, and other formations, at intervals, all the way from Dorsetshire to Yorkshire, for this fact has an important bearing on the physical history of the deposition of the Purbeck and Wealden strata, which come next in succession. Moreover, the frequent recurrence of estuarine, freshwater, and terrestrial conditions in the Lower Oolites, all the way from Northamptonshire to the north of Scotland, is suggestive of changes in the relative levels of land and sea. It indicates also conditions which afterwards culminated in the elevation of an immense continent, the nature of which is discussed in the following chapter.

CHAPTER XIV.

PURBECK AND WEALDEN STRATA.

After the discovery by Mantell of the fresh-water nature of the Hastings Sands and Weald Clay, it became customary with some geologists, led by Edward Forbes, to consider the Purbeck Beds as forming the topmost subdivision of the Oolites, and the Wealden strata as belonging to the Cretaceous Series. In reality, the interval between the marine series of the Oolitic and Lower Cretaceous epochs is, in the south of England, bridged over by the terrestrial and fluviatile episode of the Purbeck and Wealden Beds, and it is more philosophical to treat of these formations as marking one great local epoch.

For the stratigraphical arrangement of these strata in the Isle of Purbeck, see Fig. 135.

I here use the term Lower Cretaceous in the sense in which it has been applied to the Lower Greensand ever since the days of Fitton, at the same time being well aware, that all the strata above the Purbeck Beds, and up to the top of the Lower Greensand, are generally regarded as the geological equivalents of the marine Neocomian strata of the Continent.

In Lincolnshire and Yorkshire marine equivalents of part of the Wealden and Purbeck Beds exist; possibly of the whole of them, as the lowest beds of Lincolnshire (Spilsby Sandstone) contain fossils of Jurassic type, whilst the lowest Cretaceous Beds of Yorkshire, as shown by M. Pavlow and Mr. G. W. Lamplugh, have some relationship with Russian strata (Volga Beds), which are believed to link the Cretaceous with the Jurassic formations.

I have now to describe a series of deposits that were formed at or near the mouth of a river in a large delta, comparable in size to the largest deltas now forming, and consisting, in ascending order, of the Purbeck Beds, Hastings Beds, and Weald Clay.

By the deposition of the Oolitic strata, a great marine area was more or less filled with sediments, the last of which is the Portland Limestone. Aided by an extensive upheaval of these flat-lying strata, a vast tract of this area was traversed by the waters of a large continental river, the rise of land having been sufficient to unite Britain with the Continent of what is now Europe, which, however, at that time presented very different contours from those of the present day. We must now conceive the old islands, described in the last chapter, as forming groups of hills and mountains, rising out of vast plains, the surface of which consisted of horizontal or nearly horizontal Upper Oolitic strata, through which, from some far-off unknown sources, a long and broad river ran. The earliest strata of the Purbeck Beds must have been formed in open, clear, fresh water, in the broad mouth of this river, for near Tisbury in Wiltshire, and in Buckinghamshire, the marine strata of the Portland Beds and the fresh-water Purbeck Limestones are quite conformable, and are sometimes firmly united in the same quarries. The lowest beds of the Purbeck strata are, however, of fresh-water origin, and usually the junction with the uppermost marine beds of the Portland Series is abrupt.

Near the base of the Purbeck rocks, in the so-called Isles of Portland and Purbeck (Figs. 53 and 135), lie certain 'dirt beds,' which, from their colour and earthy character, were clearly ancient soils. They contain the silicified stems and stools of coniferous trees, the former procumbent and the latter with roots attached, standing in the soil in the position in which they grew. Plants such as *Mantellia*, allied to the modern Cycads, are also found in them. In the Isle of Purbeck the whole of the Purbeck strata are about 360 feet thick in their largest development. They consist chiefly of limestones and marls, principally of fresh-water origin, with interstratifications of marine, brackish-water, and terrestrial bands. In the marine bands we find fossils such as *Pecten*, *Avicula*, *Trigonia*, *Corbula*, &c. One of these, known as the 'cinder-bed,' is composed almost exclusively of oysters (*Ostrea distorta*). Along with these was found an Oolitic

Mantellia nidiformis. Ostrea distorta. Physa Bristovii. Cyrena media. Unio compressus.

FIG. 56.—GROUP OF PURBECKIAN FOSSILS.

Echinoderm, *Hemicidaris purbeckensis*. The fresh-water shells of the various beds are chiefly species of *Paludina*, *Limnæa*, *Planorbis*, *Physa*, *Valvata*, *Unio*, *Cyrena*, and *Cyclas*, and along with these are several species of small fresh-water bivalve Crustacea (Ostracoda), such as *Cypridea*, *Cypris*, &c. The celebrated Purbeck marble, so largely used in Early English architecture for the decoration of churches, lies near the top of the Upper Purbeck Beds. It is a limestone chiefly formed of remains of the fresh-water univalve, *Paludina carinifera*.

Numerous wings, elytra, and other fragments of Insects occur in thin bands in the Purbeck Limestones. Some of these (dragon-flies, &c.) are such as would live on the marshy banks of rivers. Another noteworthy fossil is the Isopod, *Archæoniscus*, specially abundant at Dinton, near Tisbury. Many Fishes have been found in the Purbeck strata; among these, *Lepidotus minor*, *Pholidophorus ornatus*, *Microdon radiatus*, *Ophiopsis breviceps*, *Hybodus*, and *Asteracanthus*, are the most characteristic. Among the Reptiles are *Goniopholis crassidens* (the Swanage Crocodile) and *Nuthetes*, also the Turtle—*Pleurosternum*, fine examples of which have been obtained at Swanage.

In 1854, portions of the jawbone of a small marsupial insectivorous Mammal, *Spalacotherium tricuspidens*, were found in a thin earthy layer in Durlston Bay, at the base of the Middle Purbeck Beds. At the close of 1856, S. H. Beckles commenced a further search in the same bed, and was rewarded by the discovery of other marsupial Mammals, *Amblotherium*, *Triconodon*, *Plagiaulax*, &c. This mammalian fauna, like that of the Stonesfield Slate, suggests comparison with the existing fauna of Australia, and the flora of the time has in part like analogies.

The Purbeck Beds are well shown in the Vale of Wardure, they appear again at Swindon, to the south-east of Oxford, and near Aylesbury.

In Sussex their occurrence was proved near Battle, by the Sub-wealden Boring, although their presence had before been suggested. There they were found to contain important beds of gypsum, a mineral also found in the Lower Purbeck Beds at Durlston Bay. The occurrence of gypsum indicates that these strata were not laid down in the sea, but probably in a lagoon temporarily separated from the main current of the river.

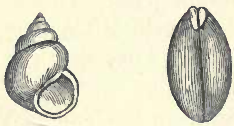
Overlying the Purbeck Beds, in the Isle of Purbeck, there are thick accumulations of sand, coloured clay, and shale, which belong to the geological horizon of the Hastings Sand and Weald Clay. They are well seen in the coast cliffs of Swanage Bay, where they contain lignite, and they occur also at Lulworth Cove.

M 2

In the Isle of Wight, strata of the same general age lie on the south-west coast, between Cowleaze Chine and the neighbourhood of Compton Bay. In these there occur *Cyrena* and *Cypris* and fragments of lignite, and similar strata with the same kinds of fossil remains are found at the northern end of Sandown Bay.

But the largest area of these fresh-water beds now exposed at the surface in England, is that of the Weald of Kent, Surrey, and Sussex, which, between the North and South Downs and the Lower Greensand, extends from Hythe on the east to the neighbourhood of Petersfield on the west. For the stratigraphical order of these strata, in this area, see diagrams (Figs. 131–133).

The Hastings Sand and Weald Clay are almost exclusively fresh-water beds, and must be considered as a continuation of the deposits formed at the mouth of the great river, which commenced with the deposition of the Purbeck Beds. The name *Wealden* applies to the group above the Purbeck Beds, and the term originated from the circumstance that these fluviatile beds are largely developed in the Wealden area before described. Their true character was first made known by Mantell and Fitton, but older writers had recognised the presence of fresh-water fossils. As a whole, the Hastings Sands form the lower portion, though they are largely interstratified with beds of clay. In the various beds are found Ferns such as *Sphenopteris*, Coniferous wood, and Cycad remains. With rare exceptions, the shells are of fresh-water genera, *Unio*, *Cyrena*, *Cyclas*, *Melanopsis*, *Neritina*, and *Paludina*, together with the Ostracod *Cypridea valdensis*. Mammalian remains belonging to genera found in the Purbeck Beds, have lately been obtained. Several remarkable Reptiles occur in the Weald, of the order Dinosauria, belonging to the genera



Paludina fluviorum. Cypridea valdensis.

FIG. 57.—WEALDEN FOSSILS.

Hylæosaurus, *Megalosaurus*, and *Iguanodon*, together with Crocodilia and Turtles. The *Iguanodon* was first described by Mantell as an herbivorous Reptile of gigantic size. Its teeth were serrated like those of the modern Iguana. Various Fishes, such as *Lepidotus*, *Hybodus*, &c., also occur in the Wealden formation.

The strata composing the Hastings Sand are about 700 feet thick. The overlying beds of Weald Clay are about 1,000 feet in thickness where most fully developed, and they spread in a broad plain, or series of low undulations, all round the more hilly country of the sands. They lie between the Hastings Sand and the overlying Lower Greensand. It is in this clay that thin bands of the well-known Sussex marble occur, so much used in old times for monumental purposes in churches, good examples of which may be seen in Westminster Abbey, in Canterbury Cathedral, and in many churches in the eastern part of the Weald. It is formed chiefly of the agglomerated shells of *Paludina fluviorum*, a form usually larger than that found in the Purbeck Marble. Interstratified with the Weald Clay in its highest part there are said to be bands sparingly charged with the remains of marine shells, such as *Ostrea distorta* and *Corbula*, which were obtained at Hythe.

Enough has now been said to prove the fresh-water and estuarine character of the Purbeck and Wealden Beds, and also, considering the broad spread of these formations in England, that they must have been deposited near the mouth of a large river. Away to the west of a great plain, through which it flowed, lay the granite hills of Devonshire, then separated by a broad flat valley from what are now the mountains of Wales. The old Mendip Hills then lay buried deep beneath the uppermost Oolitic strata, and all the ground between Wales and the high tracts of the North of England formed part of the vast plain that bordered the river; while far away, on the north, rose the majestic mountains which we now call the Highlands of Scotland, then much higher than now, for ever since that time they have been undergoing waste and degradation.

How far to the west this land spread no man can tell, but I have no doubt that Wales stood in the midst of it, for the Oolites passed out on the south through the area of what is now the Bristol Channel, and on the north across the country now occupied by the estuaries of the Mersey and Dee, and it is also very likely that at that period the whole of Ireland may have formed part of that old land. On the east our territory was undoubtedly joined to a great continent, which, after undergoing many revolutions, is now modern Europe, but it is hard to discover the details of its ancient physical geography.

CHAPTER XV.

CRETACEOUS SERIES.

When the continent described in the last chapter had endured for a long period of time, submergence of the area began to take place, accompanied by the deposition of the purely marine Cretaceous Series, which in England comprises, in ascending order, the Lower Greensand, Gault, Upper Greensand, and Chalk.

In parts of England, as before mentioned, there are strata that serve to link the Jurassic and Cretaceous Beds. These are known as the Spilsby Sandstone and Tealby Series in Lincolnshire, and the Speeton Clay in Yorkshire; they represent to a certain extent the marine equivalents of the Purbeck-Wealden Series, as well as newer strata.

In the south of England the area occupied by the Purbeck and Wealden strata underwent a long period of slow depression, and eventually the purely marine beds of the Lower Greensand began to be formed. In fact, but for the presence in it of marine fossils, it is in places hard to draw any line between the Wealden Beds and the Atherfield Clay which forms the lowest part of the Lower Greensand, and no doubt the mud that formed the latter was at first carried seaward by the same great river, in the manner, for example, that muddy sediments are now deposited at and near the mouth of the Amazons on the east coast of South America.

The *Atherfield Clay* takes its name from Atherfield, on the south-west coast of the Isle of Wight, where it is well seen overlying the Weald Clay, and is overlaid by higher beds of the Lower Greensand. Among its fossils are the well-known *Perna Mulleti*, *Trigonia caudata*, *Ostrea frons*, *Exogyra sinuata*, *Cardium Austeni*, *Pinna robinaldina*, *Arca*, *Pecten*, *Aporrhais Parkinsoni*, &c. The higher beds

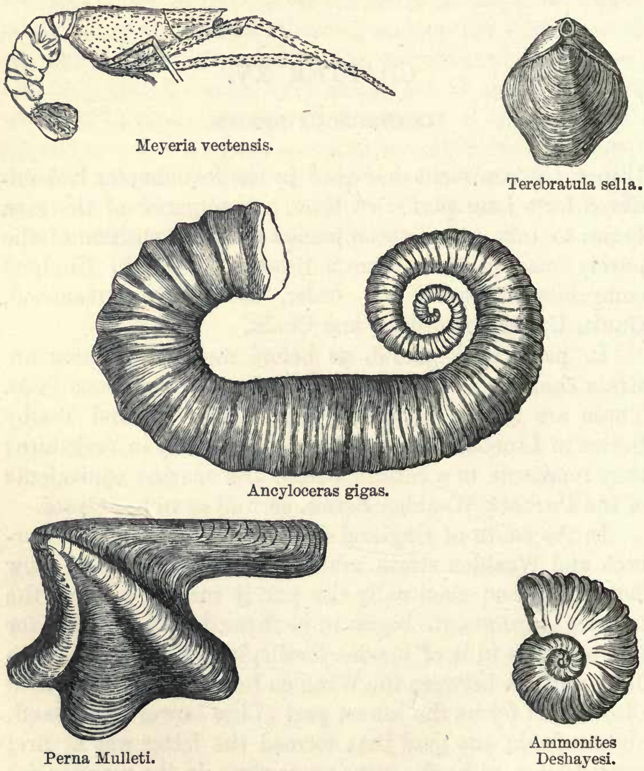


Fig. 58.—Group of Lower Greensand Fossils.

of the Lower Greensand admit of other local subdivisions; in the Isle of Wight we have the Ferruginous Sands and Sand-rock Series surmounted by the Carstone; and in the Wealden area we have the Hythe, Sandgate, and Folkestone Beds.

In the Isle of Wight, both in the Atherfield Clay and higher up in the Ferruginous Sands, there are 'Lobster Beds,' with *Meyeria vectensis*. Among other fossils we find *Ammonites Deshayesi*, *Ancyloceras gigas*, *Trigonia vectiana*, *Gervillia anceps*, *Panopæa neocomiensis*, *Pecten orbicularis*, *Arca Raulini*, *Terebratula sella*, *Rhynchonella gibbsiana*, &c. Remains of Fishes and Saurians are occasionally found. The whole of these strata overlying the Wealden Beds occur in magnificent sections along the southern cliffs of the Isle of Wight, dipping northerly under the Gault, Upper Greensand, and Chalk, which in a high ridge stretches across the island from Culver Cliff to Alum Bay. Overlaid by the Gault, and reposing on the Weald Clay, the Lower Greensand also sweeps round the Wealden area from Folkestone to Leith Hill, Guildford, Godalming, and Haslemere, and thence to near the coast north of Beachy Head. Between Guildford and Haslemere it forms high scarped terraces, and at the Devil's Punch Bowl, in the Hindhead district, it forms a prominent feature. The sands are sometimes quite soft, with intercalated hard bands, and they are frequently ferruginous.

A good building-stone, a fossiliferous and somewhat siliceous limestone, called the Kentish Rag, lies in the lower part of the formation (Hythe Beds), on the north side of the Weald at Maidstone: it rests on the Atherfield Clay. In places the Hythe Beds become very cherty, and are largely made up of siliceous sponge-spicules. Higher beds near Nutfield yield important beds of fuller's earth, and above them are sands with indurated masses of siliceous sandstone, as at Ightham, while the sands, as near Godstone, are suitable for glass-making. Near Guildford and Godalming there are pebbly beds, and these, which are cemented in places into a grit known as the 'Bargate Stone,' contain pebbles of various rocks and some derived Jurassic fossils. In Dorsetshire the Lower Greensand is seen at Punfield, north of Swanage, and at Worbarrow Bay, but it is not found west of Lulworth.

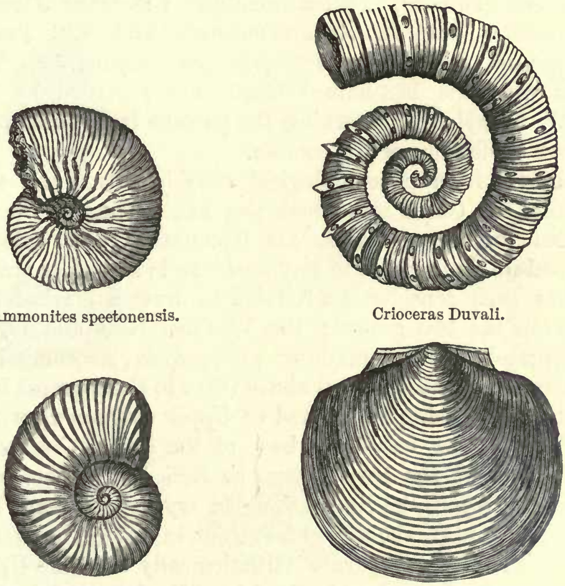
Further north, the Lower Greensand reappears in Wiltshire; and at Seend, near Devizes, where it rests on the Kimeridge Clay, it has been worked for iron-ore. In this neighbourhood it has yielded *Diceras* (*Requienia*) *Lonsdalei.*

Further on, at Faringdon in Berkshire, the formation is remarkable for the number of Calcisponges which it contains. Nowhere else, as Dr. Hinde has remarked, is such an assemblage known, for here their spicules are formed of carbonate of lime, instead of silica, as is generally the case. The most abundant genus is the *Rhaphidonema* (*Manon*), known as the 'petrified salt-cellar.'

Throughout its course the Lower Greensand is here and there overlapped by the Gault. It appears south of Abingdon, and here and there onwards to Thame and Aylesbury. Near Oxford, at Shotover Hill, and again at Brill, fresh-water fossils, *Unio*, &c., have been found, and these, which come from the lower beds, have been considered by some authorities to be Wealden; others regard the strata as fresh-water beds in the Lower Greensand. Beds of ochre and fuller's earth occur in the strata, and some of the white sands at Hartwell, near Aylesbury, have been used for glass-making. At Leighton Buzzard the Lower Greensand appears in great force, forming the Woburn Sands, and the country for miles along the pleasant region that extends to Ampthill, whence it trends away to the north-east, and disappears under the alluvium of the Fens of Cambridgeshire.

Near Woburn the beds of fuller's earth are of great economic value, while at Brickhill near by, and again at Potton, and at Wicken in Cambridgeshire, phosphatic deposits have been worked. These comprise phosphatic nodules or 'coprolites,' and many phosphatised fossils. The Isle of Ely is formed mainly of Lower Greensand, and it appears again in West Norfolk at Sandringham and Hunstanton. There it consists largely of sands with occasional clay-beds, and the sands are cemented by ferruginous matter into a hard rock known as the Carstone, which is much used for building-purposes in the neighbourhood.

The Lower Greensand reappears in Lincolnshire, skirting the Wolds on the south and west. The lowest division, the Spilsby Sandstone, contains at its base a



Ammonites speetonensis. Crioceras Duvali.

Ammonites noricus. Pecten cinctus.

FIG. 59.—GROUP OF SPEETON CLAY FOSSILS.

phosphatic band which contains Portlandian fossils. The Sandstone itself, as previously mentioned, may be of Purbeck age. It contains *Belemnites lateralis*, and is overlain by the Claxby ironstone and Tealby Beds; and from these strata *Exogyra sinuata*, *Ostrea frons*, *Pecten cinctus*, and other fossils have been obtained. The Tealby Beds are overlaid by the Carstone, and this rock, in the opinion of Mr. A. Strahan, forms the true basement-bed of the

Upper Cretaceous rocks, and should therefore be separated from the Lower Greensand. It is difficult, however, to mark this division in the Folkestone Beds and the pebbly Bargate Stone. In Yorkshire the Speeton Clay contains some of the familiar fossils of the Lower Greensand, *Ammonites Deshayesi, Panopæa neocomiensis*; lower down *Exogyra sinuata, Pecten cinctus, Crioceras Duvali, Ammonites noricus, A. speetonensis,* and still lower, *Belemnites lateralis, Ammonites gravesianus,* &c. The beds with the last-named fossils are regarded by Mr. G. W. Lamplugh as marking the passage from Jurassic to Lower Cretaceous or Neocomian.

Partly from palæontological considerations, and also because the Gault sometimes lies unconformably on the eroded surface of the Lower Greensand, and extends beyond its limits so as to rest on Jurassic and older strata, it has been considered advisable to draw a marked line between the two groups; the Wealden Beds and Lower Greensand being sometimes grouped as Neocomian or *Lower Cretaceous*, and all above them to the topmost beds of the Chalk being considered as *Upper Cretaceous* strata.

The GAULT forms the base of the *Upper Cretaceous* Series—or of the true Cretaceous Series, for those who choose to regard the Neocomian as a separate system. It is a stiff blue clay, about 300 feet thick in places, but sometimes it is hard to separate it lithologically from the Upper Greensand. It appears in the Isle of Wight, overlying the Lower Greensand, and ranges round great part of the escarpment of the Weald in the same position. It is well exposed in the low cliffs north of Folkestone, where its fossils have attracted many a collector. In the South of England, from the neighbourhood of Lyme Regis to Devizes and onwards to Lincolnshire and Yorkshire, the Gault occasionally overlaps the Lower Greensand in an unconformable manner. In proof of this unconformity, occasional outlying patches of the Lower Greensand occur north of the Chalk escarpment, as near Westbury and Seend in

Wiltshire and Faringdon in Berkshire, sometimes without any visible signs of it immediately at the base of the neighbouring Upper Cretaceous strata.

Many Foraminifera have been found in the Gault, and a few Corals, *Cyclocyathus Fittoni*, *Trochosmilia sulcata*, and *Caryophyllia Bowerbanki*. Among Sea-urchins we find *Cidaris gaultina*, *Hemiaster*, and *Diadema*. It

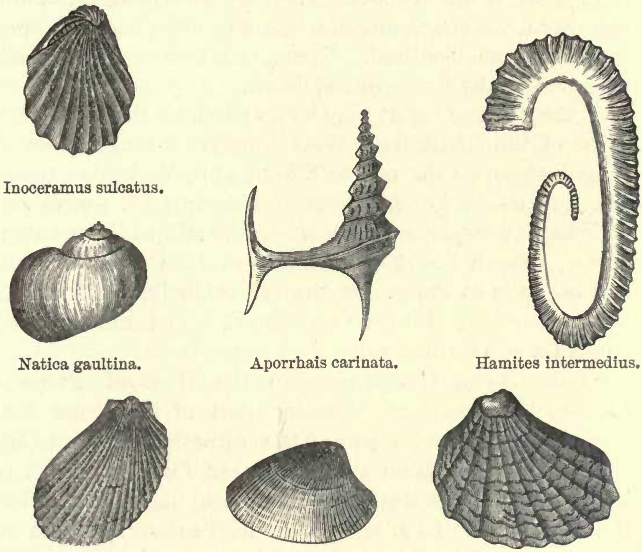


FIG. 60.—GROUP OF GAULT FOSSILS.

contains many Crustaceans, such as *Necrocarcinus*, *Palæocorystes*, &c. Among the Brachiopods and Lamellibranchs the following are characteristic:—*Terebratula biplicata*, *Kingena lima*, *Ostrea canaliculata*, *Pecten orbicularis*, *Plicatula pectinoides*, *Pinna tetragona*, *Gervillia solenoides*, *Inoceramus sulcatus*, *I. concentricus*, *Lima parallela*, *Cucullæa glabra*, *Arca carinata*, *Nucula pectinata*, *N. ovata*, &c. It also yields *Dentalium*, and

Gasteropods, *Solarium ornatum*, *Scalaria*, *Natica gaultina*, *Pleurotomaria*, *Aporrhais carinata*, &c., and many Cephalopods, such as *Belemnites minimus*, *B. ultimus*, *Nautilus Clementinus*, *Ammonites splendens*, *A. denarius*, *A. inflatus*, *A. interruptus*, *A. lautus*, *Ancyloceras spinigerum*, *Hamites intermedius*, &c. *Ammonites inflatus* characterises the upper beds ; *A. lautus*, the lower beds ; while the basement-bed is characterised by *A. mammillaris*, and this, usually a conglomeratic bed, has often been assigned to the Lower Greensand. Remains of Fishes and Saurians are occasionally found in the Gault.

Traces of the Gault may be found along the lower outskirts of the Chalk from West Norfolk, through parts of Lincolnshire, all the way to Filey Bay in Yorkshire, where the Red Chalk is over most of this area its equivalent. This bed is conspicuously shown in the cliff at Hunstanton, where, though but 4 feet in thickness, it forms a well-marked band at the base of the White Chalk, overlying the brown Carstone (Lower Greensand). It contains many characteristic Gault fossils.

THE UPPER GREENSAND in the West of England appears in great force, forming part of the strata that extend unconformably across the Jurassic rocks on to the New Red Series, from the coast near Punfield, north of Swanage, to Lyme Regis and Sidmouth, and northward to the Blackdown Hills, south-east of Taunton. West of the estuary of the Exe, it forms, in two outlying patches, the broad-topped hills of Great and Little Haldon, and near Newton Abbot there is another outlier on Milber Down. The occurrence of a patch of chert-gravel derived from Upper Greensand, and resting on the Culm-measures at Orleigh Court, three miles south-east of Bideford Bay, remains to show that the Greensand once spread westward so far, and probably much farther.

Throughout these areas, the Upper Greensand may be briefly described as consisting in its lower portion of yellowish-brown sand, partly compact, partly soft, with higher up layers and nodules of chert, and on top a calcareous sandstone. Throughout, the formation contains much glauconite, in the form of specks of silicate of iron. The sands are often coarse, and contain layers of shells, frequently broken and fragmentary. The whole is little more than 150 feet in thickness. Many of the fossils in this western region are silicified, the shells being replaced by chalcedony. Such is the case particularly in the Blackdown Hills of Devonshire, a region celebrated for its fossils. There, in years gone by, the beds were largely worked for whetstones or scythe-stones. The Blackdown Beds yield a fauna which shows that both Gault and Upper Greensand are represented in its sandy strata; and the evidence generally throughout the south of England shows that in many places the Gault and Upper Greensand constitute one formation, in some parts mainly sand, in others mainly clay, while over considerable areas it is divisible into an upper division of sandy beds and a lower of clayey beds.

The Gault, as a clayey formation, extends as far west as Lyme Regis and Honiton, but near Shaftesbury it comes on in force, and separates the Upper Greensand from the Oolitic rocks in the Vale of Wardour. The Upper Greensand is well developed near Warminster, where its organic remains, and especially the fossil Sponges, were described long ago by Miss Etheldred Benett. These include *Hallirhoa costata*, *H. agariciformis*, *Siphonia tulipa*, &c. Still further east, near Kingsclere in Hampshire, two oval tracts of Upper Greensand rise through the Chalk to the surface along an anticlinal line. It is again well shown near Devizes.

From Devizes the Upper Greensand skirts the foot of the Marlborough Downs, and extends by Wantage along the base of the Chiltern Hills by Aston Rowant to near Ivinghoe. Further north and north-east, in Cambridgeshire and Norfolk, there is no distinct appearance of Upper Greensand; beds at Cambridge which were assigned to the formation are now regarded as the base of the Chalk, and elsewhere the Red Chalk is the chief representative of the united Gault and Upper Greensand.

Returning to the South of England, we find that the Upper Greensand under Ballard Head strikes east under the sea, and reappears in the Isle of Wight, in Compton Bay below Afton Down, whence, overlying the Gault, it crosses the island to the sea at Red Cliff, under Bembridge Down.

In the area of the Weald of Kent and Sussex (Fig. 131), the Upper Greensand at the base of the escarpment of the Chalk sweeps round the vast oval, from East Wear Bay, near Folkestone, where it is but barely traceable, to near Petersfield, and thence to the sea at Eastbourne, near Beachy Head. Only here and there can the Greensand be faintly discovered, between Folkestone and Westerham. Beyond this point it begins to get more distinct, and the malm-rock, fire-stone, and hearth-stone, as different varieties are termed, can be traced all along by Godstone, Merstham, Guildford, the Hog's Back, Farnham, and the extreme west of the area in the country round Selborne and Petersfield. In some parts the Upper Greensand is hardly distinguishable from the Chalk, into which it merges; in other places it appears as a sandy marl. The cherty bands in the western area are largely composed of the siliceous spicules of sponges, while in the malm-rock and fire-stone of the Wealden area we find, as pointed out by Dr. Hinde, a matrix to a large extent formed of amorphous silica derived from sponge-spicules, with the empty casts of which the beds are filled.

The Upper Greensand is often fossiliferous, containing occasional remains of Cycads and Coniferous wood; Sponges, as before mentioned, and Corals, such as *Microbacia coronula*. Among Echinoderms we find *Discoidea*, *Cardiaster*, *Pseudodiadema*, *Salenia*, &c. Brachiopods are common, *Terebratula biplicata*, *Rhynchonella latissima*, *Terebratella pectita*, &c. In Lamellibranchs the formation is richer than the Lower Greensand, abounding especially in *Pecten asper*, *P. quinquecostatus*, *P. quadricostatus*, *Exogyra conica*, *E. columba*, *Cucullæa glabra*, *Trigonia alæformis*, *Cyprina*, and *Cytherea*. It is also rich in Gasteropods, such as *Aporrhais*, *Turritella*, *Pleurotomaria*, *Natica*, &c., and yields *Ammonites*

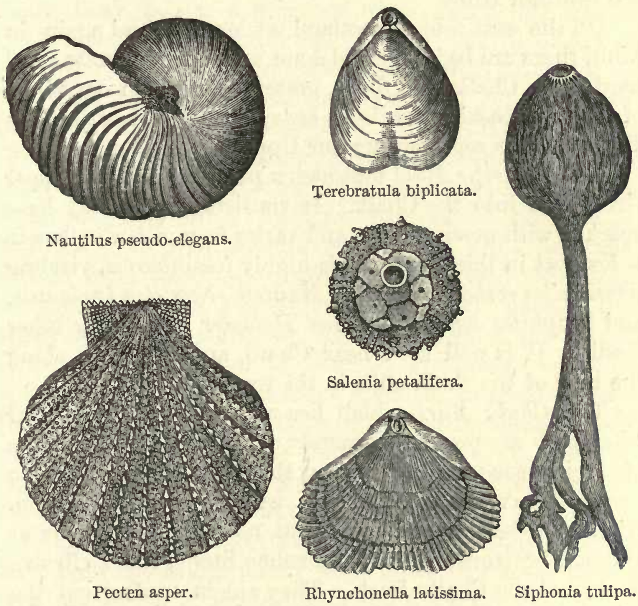


FIG. 61.—GROUP OF UPPER GREENSAND FOSSILS.

varians, *A. inflatus*, *Nautilus pseudo-elegans*, *Hamites*, *Baculites*, *Scaphites*, and *Belemnites*. Among Crustacea we find *Hoploparia longimana*, *Necrocarcinus Bechei*, &c. The Fishes include *Edaphodon*, *Lamna*, *Oxyrhina*, &c., and the Reptiles *Polyptychodon*, &c.

THE CHALK, from its familiar characters and general uniformity of structure, is the most easily recognisable of British formations. From west to east it stretches from the neighbourhood of Sidmouth and Beer in Devonshire, and Lyme Regis in Dorsetshire, to Beachy Head and the North Foreland; and passing beneath the Eocene formations of the Hampshire and London basins it spreads northward to Norfolk, Lincolnshire, and to Speeton in Yorkshire, and westward over Salisbury Plain and along the Chiltern Hills.

On the west side of Scotland, at Morven, and again in Mull, there are beds of sandstone and conglomerate, and hard white Chalk with flints, preserved beneath coverings of Tertiary basalt, and these beds have been described by Prof. Judd as representing our Upper Cretaceous rocks.

The *Chloritic Marl* indicates a passage from the Upper Greensand into the Chalk. It consists of a chalky base specked with green grains, and varies from a few inches to a few feet in thickness. It is highly fossiliferous, yielding *Ammonites rothomagensis*, *A. Mantelli*, *Nautilus lævigatus*, and *Scaphites æqualis*, besides *Holaster* and many other fossils. It is well seen near Chard, and in places along the base of the chalk cliffs in the south of England.

The *Chalk Marl*, which lies above the Chloritic Marl when both are present, is merely chalk with an admixture of argillaceous matter, and with its predecessor by no means deserves to be considered as a separate formation. Higher up harder and somewhat nodular bands occur at different horizons, as the Totternhoe Stone, the Melbourn Rock, and the Chalk Rock. They aid in tracing out the principal divisions of Lower, Middle, and Upper Chalk.

The whole formation, however, may be appropriately massed as *The Chalk*. It consists of a soft white limestone, generally much jointed where exposed in quarries, and but for layers of flints, the bedding would often be scarcely distinguishable. On minute examination with the microscope, much of the Chalk is found to consist of the shells of Foraminifera, Diatomaceæ, spicules and other remains of Sponges, Polyzoa, Echinoderms, and shells, highly comminuted. Somewhat similar deposits are now forming in the open Atlantic at great depths. In its greatest development in England the Chalk is about 1,200 feet thick in Dorsetshire, Hampshire, Norfolk, &c. The Lower Chalk, including the Totternhoe Stone, usually contains no flints and, as already stated, is marly at the base; the Middle Chalk, from the Melbourn Rock to the Chalk Rock, has as a rule few flints; while the Upper Chalk is interstratified with many beds of interrupted flints. Such characters, however, have no permanent value, for in Yorkshire the uppermost Chalk has no flints, and they are there abundant in the Middle Chalk. The flints are usually of irregular form, lying along the planes of bedding. They consist of siliceous matter that is aggregated around various organisms, very often Sponges, but also Echinoderms, Molluscs, and even Saurian teeth. The silica has been derived from sea-water by organic agency, and ultimately accumulated by a process of segregation around the organisms which served as nuclei. Some of the larger forms of flints, found in Norfolk, are known as Paramoudras, and these sometimes resemble, in general form, the large Neptune's cup sponge of the Indian Ocean. Thin oblique layers of 'tabular flint' sometimes intersect the beds of Chalk, and these must be of posterior date to the formation of the rocks they traverse.

Among the fossils of the Chalk a great many Sponges have been described, chiefly from flints; the most numerous are species of *Ventriculites* and *Siphonia* (*Choanites*) *Koenigi*, the last-named being frequently present in the Isle of Wight and Brighton flint-pebbles that are polished and sold to visitors. A large number of genera and species of Foraminifera are also described, among which *Globigerina*, *Dentalina*, and *Cristellaria* are common. Of Corals, several belong to the genera *Parasmilia*, *Caryophyllia*, &c. Echinoderms are very numerous; among others we find *Echinocorys vulgaris* (*Ananchytes ovatus*), *Galerites albogalerus*, *Marsupites*, *Micraster coranguinum*, *Cardiaster*, *Holaster subglobosus*, *Cyphosoma Koenigi*, and a Star-fish

Goniaster. Polyzoa are numerous. Among Brachiopods there are *Terebratula carnea*, *T. obesa*, *T. semiglobosa*,

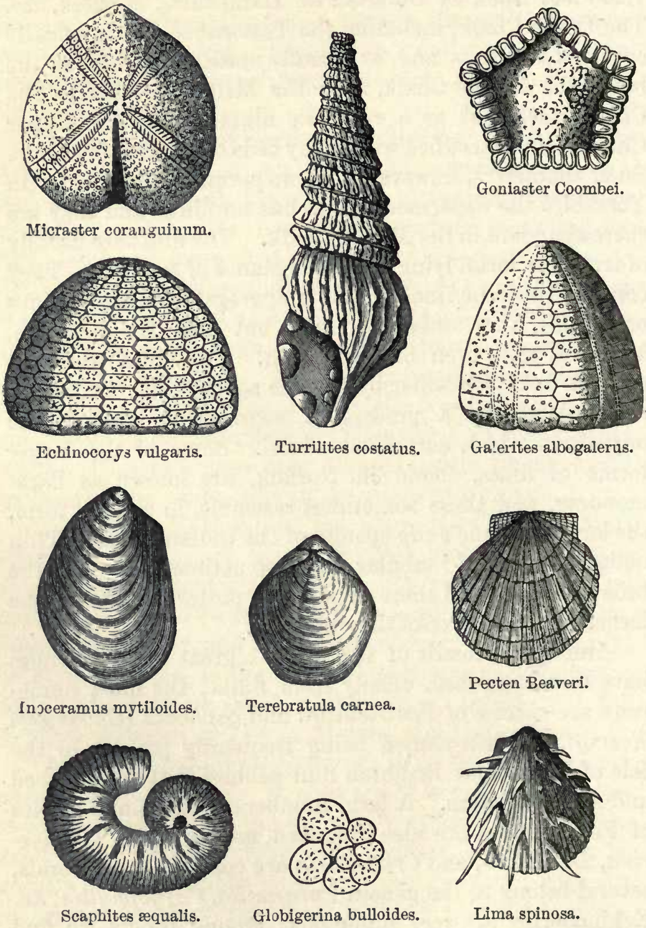


FIG. 62.—GROUP OF CHALK FOSSILS.

Terebratulina gracilis, *Rhynchonella plicatilis*, *R. Cuvieri*, &c. The Lamellibranchs include *Lima spinosa*, *Pecten*

Beaveri, *Inoceramus mytiloides*, and *Ostrea vesicularis*. Gasteropods are as a rule poorly preserved and far from abundant; among them *Pleurotomaria* is found. Of the Cephalopods, Ammonites are found chiefly in the lower beds, and they include *Ammonites peramplus* and *A. varians*, as well as forms already noted from the Chloritic Marl. *Turrilites costatus* and species of *Hamites* and *Baculites* occur in the Lower Chalk. Most of the fossils have their characteristic horizons, and the Chalk is divided into a number of zones, named according to some prominent index-form. In the highest stage *Belemnitella mucronata* is abundant, while *B. plena* characterises a stage in the Lower Chalk; other fossils, Brachiopods, Echinoderms, &c., similarly characterise stages in the Chalk, because there they are most abundant, though not necessarily confined within arbitrary limits.

The Fishes include species of *Notidanus*, *Lamna*, *Ptychodus*, *Beryx*, &c. Among Reptiles the *Leiodon* (*Mosasaurus*) is conspicuous, and there are also found the Pterodactyl *Ornithocheirus* and Turtle *Cimoliochelys*. Remains of Birds, *Enaliornis*, have been found in the 'Cambridge Greensand,' the basement-bed of the Chalk, which has been largely worked for the phosphatic nodules which it contains.

Having thus briefly described the Upper Cretaceous strata of England, I shall next endeavour to show what inferences may be drawn with regard to the physical geography of the British area during the period of their formation.

We have already seen that, during the deposition of the Purbeck and Wealden strata, England formed part of a great continent, and that, during the formation of the Lower Greensand, this land suffered partial submergence, but by no means to such an extent that the Oolitic strata, which then extended far to the west, round Wales, were entirely sunk beneath the sea in which our Lower Greensand was deposited.

As a whole, the Lower Greensand, being a coarse and sandy formation, was deposited in shallow water, and great part of it was afterwards subjected to waste before or during the time of the deposition of the Gault. The deposition of the Gault in our area first took place on a surface of country that was being gradually submerged, and part of the sediment was laid on the Lower Greensand, and part on various members of the Oolitic strata, from which the Lower Greensand had been removed by denudation. This Gault Clay, as previously mentioned, is intimately associated with the Upper Greensand, while the latter in places merges into the Chalk, so that, except as local developments of different sedimentary character, they ought to be considered, on a broad scale, as only one formation.

The Upper Greensand was deposited in the far west on a sea-bottom that now forms an eastern part of Devonshire. Not far from its margin, a fragment of the old land, in our day known in a modified form as the granite hills of Dartmoor, stood high above the level of the sea, and at the same time, on the opposite side of what is now the Bristol Channel, Wales also formed high land. The pebbly shore of the lower land near Dartmoor has long ago been destroyed by denudation, but the sediments laid down not far from the shore still exist in the coarse sandy strata that form the Upper Greensand of Haldon and the Blackdown Hills. As we go eastward from that area towards Devizes, the Upper Greensand still continues to be comparatively coarse, and by degrees in Berkshire, Oxfordshire, and Buckinghamshire, it gets finer and finer, and at length becomes white, calcareous, and marly, and, as it were, seems to mingle with the Gault beneath and the Chalk above.

In like manner, at the western end of the Wealden area, and along the base of the South and North Downs, the Upper Greensand for many miles consists of fine white sand, and in the Malm-rock is somewhat chalk-like, siliceous, and calcareous, till going further east towards

Folkestone, it gradually becomes untraceable as a special formation, and we have, as at Burham, little but the Gault which forms a clayey base to the Chalk formation.

The meaning of this is, that distinct coarse Upper Greensand strata were deposited not far from shore in the west, gradually getting finer towards the east, because the lighter material was drifted further from shore. At the same time, in the farther east of what is now England, the sediments were still finer, and depositions akin to Chalk, as in the Red Chalk of Hunstanton, and even the Chalk itself, had begun to be formed in a deeper sea, far removed from land, so that, according to this view, part of the lowest strata of the Chalk, in the eastern and south-eastern parts of England, were deposited contemporaneously with the coarse Upper Greensand of eastern Devonshire. On no other hypothesis than this, formulated years ago by Godwin-Austen, can the phenomena connected with the Gault, Upper Greensand, and the lower strata of the Chalk, be rationally accounted for.

As the upper strata of the Chalk accumulated, the sinking of the western and northern fragments of the old continent steadily continued, till at length they almost, if not entirely, sank beneath a sea, like the Atlantic of our own time, for though it may not have been so deep as some parts of the present Atlantic, yet the old and the new seas are akin in the nature of their organic sediments. Possibly a few insignificant islets rose above a waste of waters, that spread not only over Britain, but also over a large part of the Europe of the present day, long before the Alps and the Pyrenees rose into mountain chains.

A vast lapse of time took place between the close of the deposition of the uppermost Cretaceous strata of England and the commencement of the succeeding Eocene formations, for in England we have no deposits of intermediate age. What, however, helps to prove this hiatus is, that in Holland and Denmark there are calcareous beds containing *Baculites*, *Hamites*, and other Chalk fossils, together with

Voluta, *Cypræa*, *Oliva*, and other genera that characterise our Tertiary strata. This formation by its fauna is intermediate in date to the ordinary Cretaceous and Eocene strata.

Without such data as these it is evident to any reflective mind, that a great gap in time, unrepresented by any sedimentary formations in England, took place in our area between the deposition of the latest bed of Chalk and that of the earliest Eocene stratum. For, excepting a few Foraminifera, the species found in the Chalk seem all to have been remodelled before our Eocene epoch began, while the sedimentary materials, the pebble-beds and even, to some extent, the sands of these newer deposits, are made up of fragments of Chalk flints.

CHAPTER XVI.

EOCENE STRATA.

THE EOCENE STRATA, to which we have now come in this epitome of British geological history, form the oldest members of the Tertiary or Cainozoic system. It ought, however, to be remembered, that the terms Palæozoic or Primary, Mesozoic or Secondary, and Cænozoic or Tertiary, are mere terms of local convenience, unfit even for minor territories such as Europe, as shown at the end of the last chapter, in the notice of strata intermediate to the Chalk and Eocene Beds.

The Eocene strata of England lie in two basins, those of London and Hampshire. Both are underlain by the Chalk. The London basin extends westward from the mouth of the estuary of the Thames to the neighbourhood of Marlborough, and northward till it is lost beneath the drift of Suffolk and Norfolk. The northern boundary of the Hampshire basin runs from Beachy Head to the neighbourhood of Salisbury and Dorchester. The Chalk Downs of the Isle of Wight form its southern boundary. In this basin the Oligocene strata also occur. In both areas the Chalk and Tertiary strata are little disturbed, except in the Isle of Wight and at Purbeck, where for a space they have been heaved nearly on end. The Eocene deposits lie sometimes on upper beds of Chalk, and sometimes on beds lower in the series, as in the case of the Oldhaven Beds near Caterham. They are, therefore, highly *unconformable* to each other, and this alone marks a great interval of time, unrepresented in Britain by the deposition of strata; for great continental areas of Chalk were raised above the sea and remained as dry land for a period of time so long, that, when they were again submerged, the life of Cretaceous times had mostly been remodelled by slow evolution, and newer forms in time became the legitimate successors of their long-buried ancestors.

The strata of the above-mentioned basins were not originally deposited in two distinct hollows; they were once united, and formed one great area of Eocene age. Long after, a disturbance of the Secondary and Lower Tertiary strata took place, which threw them into anticlinal and synclinal curves. One long and broad anticlinal curve passes along the Wealden area from east to west, and still further on through part of the Chalk. South of this we find the synclinal curve of the Hampshire basin, bounded on the south by the Cretaceous strata of the Isles of Wight and Purbeck, and on the north by the Chalk of the Salisbury, Winchester, and Brighton area; while north of the Weald, the Eocene strata of the London basin, bounded by Chalk, lie in a similar synclinal curve, broad at its east or seaward end, and narrow at its western end towards Marlborough. When closely examined, it is found that many of our Eocene and Oligocene strata were deposited in fresh and in brackish water, and others in the sea, and the conclusion to be drawn from this is, that they largely consist of sediments that were thrown down at the mouth of a great river. The various subdivisions of the strata are given in the Table of British Formations (p. 47).

The *Thanet Sands*, so named by Prof. Prestwich because they are so well developed in the Isle of Thanet, may be studied in the cliffs of Pegwell Bay, and the Reculvers, near Herne Bay. They form the base of the Eocene strata of England, and consist of fine light-coloured sands, partly mixed with clayey matter. At the base there is usually a layer of Chalk flints, of an olive-green colour externally, and this probably represents the effect of the underground waste of the Chalk which was carried away in solution as bicarbonate, through the infiltration of rain-water after the deposition of the sands. These sands range from the Isle of Thanet westward to the neighbourhood of London, and northward to Sudbury; but they are unknown in the Hampshire basin. Their maximum thickness is about 70 feet.

The fossils of this subformation are marine. Among these are a shark of the genus *Lamna*; a *Nautilus*; Gasteropods, such as *Fusus subnodosus*, *Scalaria Bowerbanki*,

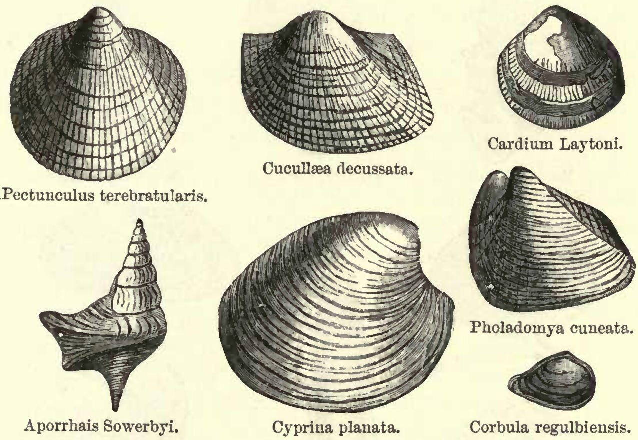


FIG. 63.—GROUP OF THANET SAND FOSSILS.

Aporrhais Sowerbyi; Lamellibranchs, such as *Cyprina Morrisi*, *C. planata*, *Pholadomya Konincki*, *P. cuneata*, *Corbula regulbiensis*, *Cucullæa decussata*, *Pectunculus terebratularis*, *Cardium Laytoni*, &c.

The *Woolwich and Reading Beds* overlie the Thanet Sands, and, when that formation is absent, rest directly on the Chalk, as in the western part of the London basin, in Hampshire and the Isle of Wight. They consist of mottled clays, light-grey sands, and of pebble-beds, made of chalk-flints. These are sometimes loose and gravelly, and sometimes hardened, as in the case of the Hertfordshire pudding-stone. From west to east the strata vary from 15 to 90 feet thick in the London basin, and from 80 to 160 feet in the Hampshire basin (Fig. 70). In Hampshire and the Isle of Wight the formation consists of mingled marine, estuarine, and often of purely fresh-water strata, marking

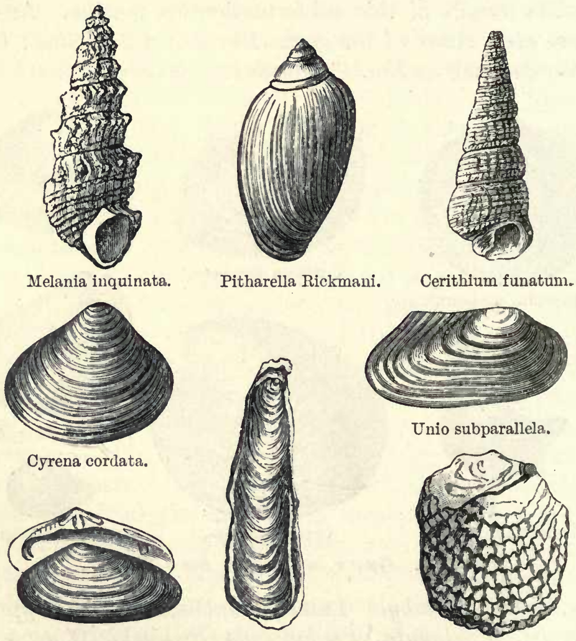


Fig. 64.—Group of Fossils from the Woolwich and Reading Beds.

the first obvious signs of the influx of a great river, formed by the drainage of a continent, the result of the upheaval above the sea of large areas of Chalk and other older rocks in what is now Britain and elsewhere. Similar variable conditions, commencing with marine beds, are indicated by the strata at Reading. At Woolwich the beds are chiefly estuarine, and further east chiefly marine.

The fossils in the Woolwich and Reading strata include an herbivorous Mammal of the genus *Coryphodon*, allied to the modern tapir, also bones of Birds, such as *Gastornis*, and remains of Turtles and Crocodiles. Among Fishes we find *Lamna* and *Lepidotus*. The Gasteropods include *Cerithium* (*Potamides*) *funatum*, *Fusus latus*, *Hydrobia Parkinsoni*, *Natica*, *Neritina*, *Pitharella Rickmani*, *Melania inquinata*, *Paludina lenta*, and others. The Lamellibranchs comprise *Cardium*, *Corbula*, *Cyrena cordata*, *C. tellinella*, *Modiola*, *Ostrea Bellovacina*, *O. tenera*, *Unio subparallela*, *Pectunculus*, *Psammobia*, &c. A number of land-plants have been found, and these include the Fig, Laurel, Aralia, &c., and are considered by Mr. J. Starkie Gardner to indicate rather a temperate climate as compared with the Lower Bagshot flora.

The *Oldhaven and Blackheath Beds* lie between the Woolwich and Reading Beds and the London Clay. They consist of fine sand and shingle made up mainly of water-worn pebbles of flint. They are from 30 to 40 feet thick, and local in occurrence. They are not met with under London, but occur to the east of it, and as far north as Ipswich. A large number of fossils are recorded by Mr. Whitaker, but these mainly occur at the base of the formation. They comprise marine and estuarine Mollusca, the estuarine forms being more closely allied to those of the Woolwich and Reading Beds, and the marine forms to those of the London Clay. The pebble-beds being so free from any subangular material, Mr. Whitaker considers that they must have been deposited some way off the shore, as a bank to which no stones could get until they had been long exposed to wearing action. A few pebbles of quartzite have been found.

The *London Clay* is a marine deposit, and usually consists of bluish-grey clay, weathering brown at the surface, and with occasional bands of septaria. In thickness the London Clay varies from about 220 feet in the Isle of Wight to nearly 500 feet in the London basin. As a rule the formation is far from fossiliferous, and it is mainly in deep excavations, where the beds are unweathered, and in cliffs where they are subject to denudation, that most of the specimens have been obtained. The chief fossiliferous locality in the Hampshire basin is at Bognor in Sussex, but fossils may also be found in Alum and Whitecliff Bays in the Isle of Wight. Round London they have been obtained at Highgate, and in other places. The Isle of Sheppey has long been famous for its fossils, being found there chiefly because of the frequent landslips from the cliffs that overlook the estuary of the Thames. The plants consist of remains of Screw-pines, *Nipa elliptica*, and other fruits; Palms, and plants allied to the Cypress, Myrtle, Mimosa, &c., indicating a somewhat tropical climate.

Remains occur of Birds allied to the vulture, *Lithornis*; the albatross, *Argillornis*; the kingfisher, *Halcyornis*; and to the heron, *Odontopteryx*. Turtles and river Tortoises are numerous, and they belong to the genera *Argillochelys*, *Podocnemis*, *Chelone*, and *Trionyx*; there are also remains of the Crocodile, *Crocodilus*, and of Serpents, *Palæophis*. Some Mammals likewise occur—a marsupial, *Didelphys*, and ungulates, such as *Hyracotherium* and *Coryphodon*.

Plants, Birds, Reptiles, and Mammals all tell of the immediate neighbourhood of land, and the marine fossils now to be mentioned seem in fact to have lived at the mouth of a great river.

Many Fishes have been noted from the London Clay, including species of *Lamna*, and of Rays, *Myliobatis*. Of the Cephalopods, *Nautilus imperialis* is common. Ammonites and Belemnites, genera common in the Cretaceous strata, have disappeared. Among Gasteropods the most prominent are *Fusus bifasciatus*, *F. tuberosus*, *Murex subcristatus*, *M. spinulosus*, *Pleurotoma prisca*, *Voluta nodosa*, *V. Wetherelli*, *Pyrula Smithi*, *Cassidaria striata*, and *Rostellaria ampla*. Lamellibranchs include *Pectunculus brevirostris*, *P. decussatus*, *Pinna affinis*, *Pholadomya margaritacea*, &c. The Brachiopods are represented by

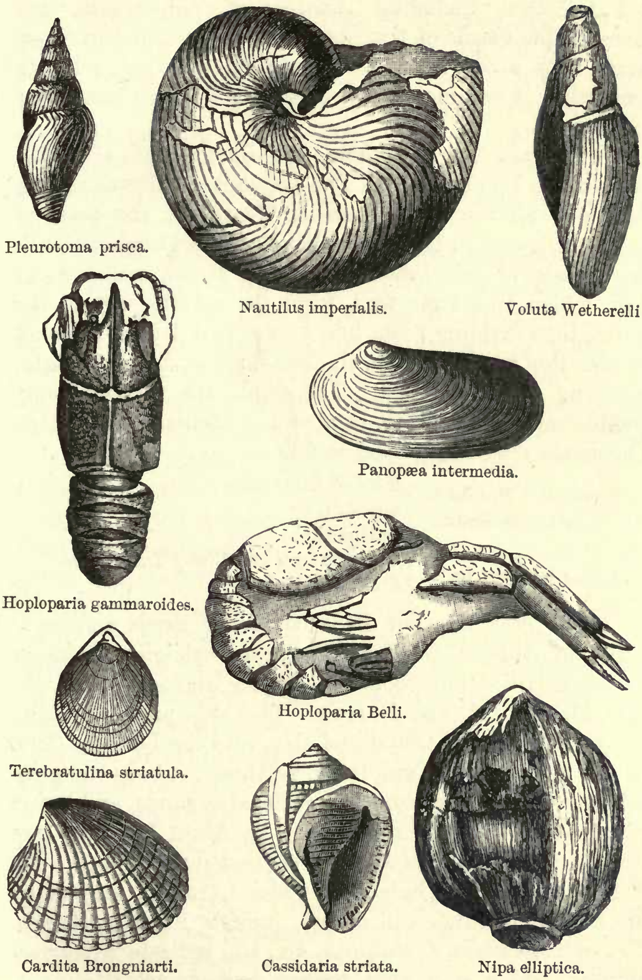


Fig. 65.—Group of London Clay Fossils.

Lingula tenuis and *Terebratulina striatula*, and there are a few Polyzoa. Crustacea are numerous, especially Crabs and Lobsters, including *Xanthopsis*, *Hoploparia*, &c. Many of the fossils of the London Clay are found in other strata both above and below that formation, but a larger proportion is common to the overlying than to the lower formations.

The *Bagshot*, *Bracklesham*, and *Barton Beds* (Fig. 70) succeed the London Clay. The Bagshot and Bracklesham Beds are well shown on Bagshot Heath, on the coast of Hampshire, and in the Isle of Wight. On Bagshot Heath they consist of light-brown and yellow sands, with beds of clay, which, in a rude way, form the middle part of the strata, thus dividing them into Lower and Upper Bagshot Sands, the whole, where thickest in the London basin, attaining about 300 feet. The sands are very sparingly fossiliferous, but the clay, in places, contains a few species. The strata may be grouped as follows :—

Upper and Middle Bagshot Beds	Headon Hill Sands Barton Clay Bracklesham Beds
Lower Bagshot Beds	Bournemouth and Bovey Tracey Beds Alum Bay Beds

The Lower Bagshot Beds consist of sands and occasional pebble-beds. Outliers occur near Rayleigh in Essex, at Langdon Hill, Brentwood, and Epping, and again at Highgate, Hampstead, and Harrow. The beds pass gradually, or by alternations of sand and clay, into the London Clay. In the Isle of Wight and in Dorsetshire the beds comprise brightly coloured crimson and variegated sands, and layers of pipe-clay with plant-remains. In Alum Bay they are well seen, and their thickness is estimated at 660 feet. (See Fig. 70, p. 205.) The plants, which have been studied by Mr. Starkie Gardner and others, include the Fig, *Aralia*, *Dryandra*, *Cassia*, *Cæsalpina*, &c., and indicate a tropical climate. At a somewhat higher horizon are the plant-beds of Bournemouth in Dorsetshire, and of Bovey Tracey in Devonshire, the latter for long considered to be of Miocene age. The Bournemouth Beds yield many Ferns, also *Nipa*, *Sequoia*, *Eucalyptus*, *Araucaria*, &c.; and the Bovey Tracey Beds yield the huge coniferous tree *Sequoia*, also *Cinnamomum*, Vines, Laurels, Water-lilies, and numerous Ferns. In this series of beds we have important economic products in the potter's clays of Poole in Dorset, and of Newton Abbot in Devonshire; while the lignite beds, or Bovey Coal, of Bovey Tracey have proved of local service as a fuel.

At a still higher horizon are the rich fossiliferous beds of Bracklesham, in Sussex, which comprise beds of sand and sandy clay, often of a greenish colour, together with marls. The Bracklesham Beds are exposed in Alum and Whitecliff Bays, in the Isle of Wight, and also on the Hampshire coast near Bournemouth. Gasteropods are numerous, and many of them have a tropical aspect. They include *Cypræa Bowerbanki*, *Murex asper*, *M. minax*, *Conus deperditus*, *Cerithium giganteum*, *Ancillaria fusiformis*, *Turritella imbricataria*, *Pleurotoma attenuata*, &c. Conspicuous among Lamellibranchs is the *Cardita planicosta*, and we find also *Ostrea flabellula*, *Corbula pisum*, *Sanguinolaria Hollowaysi*, *Arca biangula*, &c. In places the Coral *Litharæa* is found, and noteworthy are Foraminifera, such as *Nummulites lævigatus*. Among Fishes we find *Myliobatis*. In the same set of rocks there have also been found a Serpent, *Palæophis typhæus*, which may have been 20 feet in length; a Turtle, *Lytoloma trigoniceps*; a Crocodile, *Gavialis*; and a tapiroid Mammal, *Lophiodon*.

The *Barton Clay*, exposed in the cliffs of Barton and Hordwell, on the south-west of Lymington in Hampshire, is quite a local deposit; it overlies the Bracklesham Beds, and may belong to the Upper Bagshot Beds. It is especially fossiliferous, containing a Cetacean, *Zeuglodon*; an 'Alligator,' *Diplocynodon*; Fishes, such as *Lamna* and *Myliobatis*; and an abundance of marine shells. These have in general a tropical character, and many of the species are found also in the Bracklesham Beds, and some in the Headon Beds above. Among them are *Rostellaria*

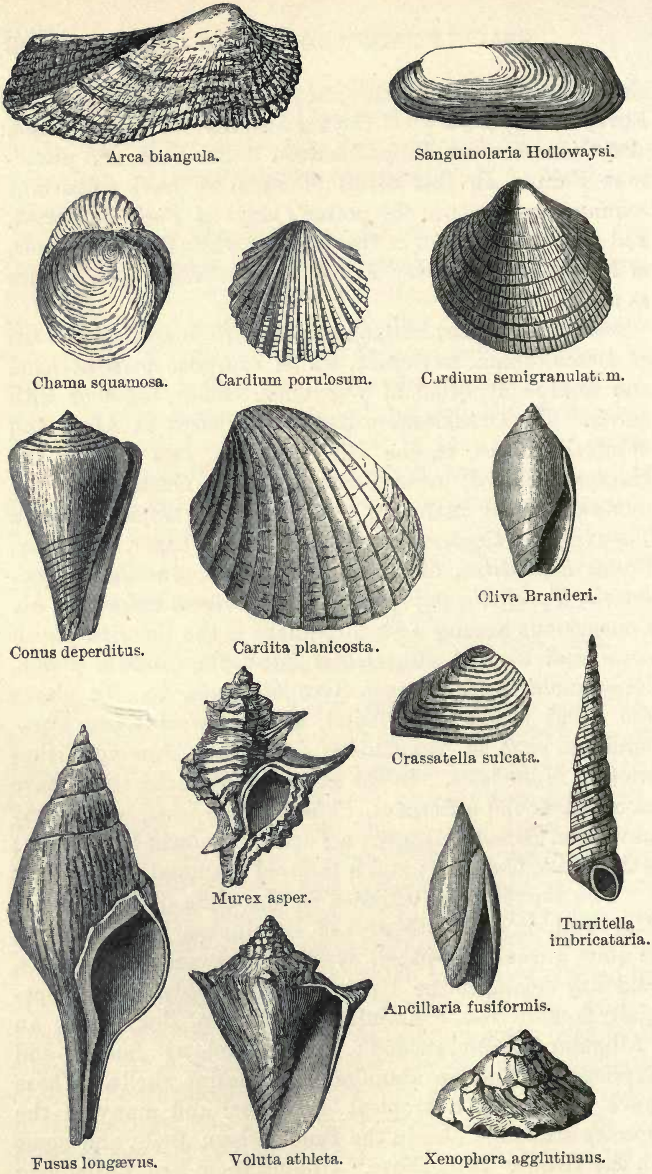


FIG. 66.—GROUP OF FOSSILS FROM THE BRACKLESHAM AND BARTON BEDS

rimosa, *Typhis pungens*, *Xenophora* (*Phorus*) *agglutinans* *Fusus longævus*, *F. pyrus*, *Voluta athleta*, *V. luctatrix*, *Oliva Branderi*, *Chama squamosa*, *Crassatella sulcata*, *Cardium semigranulatum*, *C. porulosum*, &c. The Foraminifer *Nummulites elegans* also occurs in the Barton Clay.

The Eocene strata of England taken as a whole may be looked upon as estuarine beds. The Woolwich and Reading Beds, and portions of the Bagshot Beds in the Isle of Wight and Hampshire, consist of strata deposited in brackish and fresh water, at or near the mouth of a great river. After the marine Thanet Beds were laid down, the estuarine conditions of the Woolwich and Reading Beds set in. These conditions were still going on when the London Clay was thrown down; with this difference, that by sinking of the area, the estuary had become longer, wider, and deeper, but still remained connected with a vast continent through which the Eocene river flowed. The abundance of plants and terrestrial remains in the London Clay proves that it was deposited near the mouth of a great river, comparable to the Ganges, the Mississippi, and the Amazons. These Eocene strata contain a large terrestrial Mammalian fauna, the genera of which are so antique that they have no very close relation with those now living; nevertheless, some are doubtless the direct ancestors of existing species through Miocene and Pliocene intermediate forms. To give an idea of the antiquity of this old fauna, it is safe to say that when it flourished the Alps had scarcely any place as a principal mountain range.

In the Isle of Wight, the beds of lignite found in the Bagshot Beds overlie clays with rootlets. These clays play the same part to the Eocene lignites that the underclays do to the beds of coal in the Coal-measures, thus telling of marshes in the broad flats of the Eocene delta, where vegetation growing and decaying formed beds of peat, that subsequently, buried under newer strata, became converted into lignite.

As yet I know of no data that tend to show from what direction this continental Eocene river flowed, or, in other words, what were the general shape and bearings of this vast Eocene continent. Of this, however, we may be sure, that somewhat altered in form and somewhat lowered by waste, the old Silurian lands of Wales, the north of England, and the Scottish mountains formed part of the Continent that gave birth to the Eocene river. The Eocene formations of the London basin all thin away as we pass from east to west, and it seems as if originally there had been a landward edge to the estuary in that direction, and possibly the river may have flowed through wide lands that stretched far to the west and north-west, or, on the other hand, it may have flowed through broad tracts of what is now part of the Continent of Europe. The occurrence of the Bovey Beds points to an old lake, the sands and clays having been derived from the waste of the neighbouring Greensand and the granite of Dartmoor; while the vegetable matter that now forms the lignites was derived from the plants that bordered the lake or were drifted into it from higher sources. The white clays, like the China clays of Cornwall, are clearly due to the disintegration of the felspars of the granite. It would seem that the Poole clays must have had a similar origin, though their distance from any known granite is great. However that may be, I have no doubt that large tributary streams poured into the main river from the west and north-west, for to my mind it is certain, that beyond the original edge of these Eocene formations, the Chalk spread far to the west and north-west, to the region of Antrim and the Cretaceous rocks of the Western Isles of Scotland, which then formed part of the mainland, before those volcanic eruptions took place that overspread part of Antrim with sheets of basalt, and gave rise to the present mountain scenery of the Inner Hebrides.

In the island of Mull, and on the mainland opposite, in Staffa, Rum, Muck, Eigg, Canna, Skye, and Raasay, the early Tertiary rocks consist in part of sills and eruptive bosses, and in part of the lava-flows and ashes of great terrestrial volcanoes. The lavas, as they accumulated, overflowed and filled up the undulating valleys of the Secondary and older rocks in what is now the west of Scotland, and in the intervals of eruptions lakes were sometimes formed, and terrestrial soils accumulated on the sides of volcanoes. Some of these, according to Professor Judd, grew by accretion of volcanic matter till they rivalled Etna in height, and seemed as if they might last for ever, but being diminished by central subsidence and long-continued sub-aerial waste, the mountain of Beinn More in Mull is now little over 3,000 feet in height.

In Mull, at the headland of Ardtun, the Duke of Argyll discovered in 1851 thin leaf-bearing beds of shale, intercalated among beds of basaltic lava, tuffs or volcanic ashes. As remarked by Mr. J. Starkie Gardner, the value of this discovery to the geologist can hardly be overestimated, for the data then furnished materially assisted to determine the age of the volcanic rocks that stretch from Antrim to Greenland. The plant-remains, though considered by Heer to be of Miocene age, are now recognised by Mr. Gardner to be of earlier Tertiary age. These remains include a conifer, *Sequoia*, together with *Glyptostrobus*, *Quercites*, *Corylites*, a plane tree, *Platanus*, and Ferns.

Associated with the volcanic rocks of Skye, similar phenomena occur; and at Portree there was formerly a ‘coal-mine’ where Tertiary lignite was obtained.

It is remarkable that these Plant Beds have yielded so few traces of animal life—only, as a rule, scanty remains of Insects.

The volcanic rocks of the Inner Hebrides consist chiefly of Basalt, Dolerite, Gabbro, and Granophyre, and also of agglomerates. While the earliest eruptions date back to the Eocene, yet, as Sir Archibald Geikie has remarked, the final manifestations may not have ceased until Miocene times. The volcanic outbreaks seem to have commenced with eruptions of lava that are now seen in the great basalt-plateaux and in the countless dykes that penetrate the older rocks. Later on, more coarsely crystalline basic rocks, such as dolerite and gabbro, rose through the earlier bedded basalts, in huge bosses, so well exhibited in the Cuillin Hills of Skye. Again renewed outbreaks took place, and this time of an acid type, so well shown in the Red Hills of Skye, in the granitic rocks known as granophyre. These rocks, as Sir A. Geikie has shown, 'not only ascended through the basalt-plateaux and the gabbro-bosses; they sent into these rocks a network of veins, and pushed their way in huge sheets or sills between the strata below.' The gabbro is well seen in Rum and again at Ardnamurchan Point, on the mainland.

It is clear that the beds of lignite in these Western Isles, and the shales with leaves, indicate long pauses here and there in the activity of many eruptions of the earlier bedded basalts, which in places must be from 2,000 to 3,000 feet thick. Vegetation on a large scale had time to flourish. The denuded edges of the several lava-streams now form a wonderful series of terraces, rising tier upon tier, like Titanic steps, high on the hills on both sides of the Sound of Mull; and the splendid columnar basalt of Fingal's Cave, in Staffa, is known to all tourists among the Inner Hebrides (see Fig. 67). The columnar structure of Staffa, and the prismatic structure seen in some of the sills, as in the Kilt Rock, near Loch Staffin, in Skye, owe their origin to a kind of jointing produced during the solidification and contraction of the molten rock. The terraced forms of the basalts are prominent in Macleod's Tables, in Skye, and in many of the smaller islands. But the craters from which these vast volcanic piles of lavas and ashes were ejected are all gone and utterly wasted away, and only their deep-seated roots remain to mark the sites. It is a remarkable circumstance, and worthy to be noted, that while the bedded basalts were erupted at the surface, the deep-seated centres of more coarsely crystalline rock—

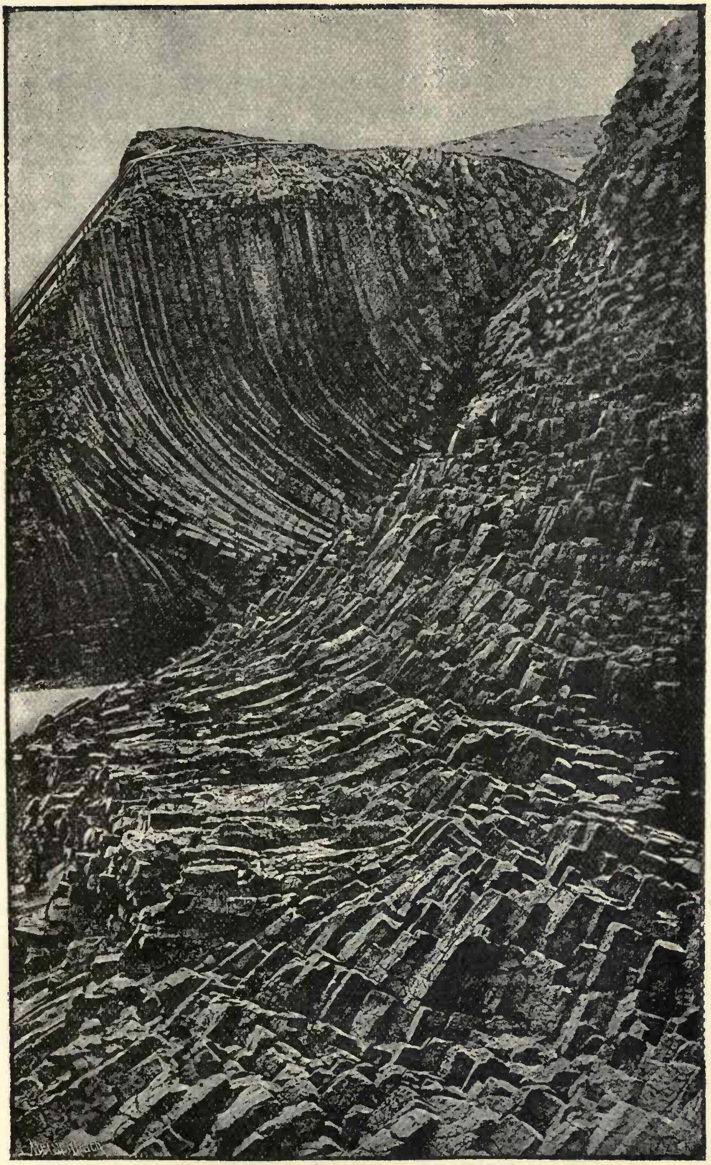


Fig. 67.—Curved Columnar Structure in Basalt, Isle of Staffa. (J. G.)

the granophyres and gabbros—are now apt to form some of the highest portions of the islands. They have been bared by denudation, and their hardness helps to preserve them.

Long before these extreme denudations took place, when the islands formed part of a wide-spreading territory, old river-beds intersected it. These rivers scooped out valleys in the lavas and tuffs, which were again partly filled by torrents of basalt, and even of acid rock, such as pitchstone. In the case of the Scuir of Eigg, the pitchstone, as described by Sir A. Geikie[1] (see Fig. 68), flowed over

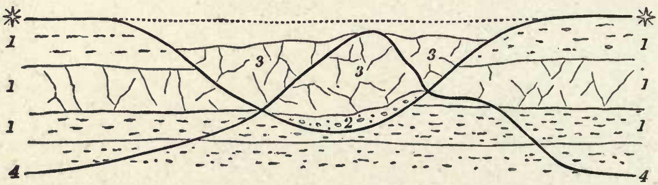


FIG. 68.—DIAGRAM TO SHOW THE ORIGIN OF THE SCUIR OF EIGG.

1. Old lavas, &c. 2. Old river valley scooped out by denudation. * Outline of country before the eruption of 3. 3. Pitchstone filling valley. 4. Present outline of country produced by later denudations of No. 1 and part of 3.

the valley gravel (2) and buried it. Since then the waste has been so great, that the destruction of the older hills that bounded the valley has literally exalted the valley and laid the hills low, for the pitchstone was harder than the walls of the valley, and has longer resisted destruction, and thus it happened that the Scuir of Eigg became one of the most striking points among the Western Islands. The summit of Raasay, Dun Caan, is formed of a small craggy outlier of basalt, not unlike in appearance to the Scuir of Eigg.

It is possible that some of the eruptive dykes in the

[1] See 'The History of Volcanic Action during the Tertiary Period in the British Isles,' *Trans. Roy. Soc. Edin.*, vol. xxxv. p. 178. On this subject see also Judd, 'On the Ancient Volcanoes of the Highlands,' *Quart. Journ. Geol. Soc.*, vol. xxx. p. 220.

north of England may be of Tertiary age. The Cleveland dyke, an augite-andesite, which is intrusive in the Lias and Oolites, appears south of Whitby, and extends in a westerly direction for more than ninety miles. This dyke may, in the opinion of Mr. Teall, be of Tertiary age.

Such is a general sketch of the physical geography of Britain during the Eocene epoch, when our land formed part of a continent, differing in many great details from modern Europe, which, in its physical geography, underwent most important modifications during the Oligocene and Miocene periods. Other great local changes afterwards brought the Miocene epoch to a close. I use such terms as these for want of better, for since the beginning of geological time, no epoch had either a definite beginning or a definite end, and, in a world-wide scale, the various epochs merged into each other like the colours in a rainbow, or the so-called epochs of the history of nations, which have only a local significance, when they are taken in connection with the history of the whole human race.

CHAPTER XVII.

OLIGOCENE STRATA.

THE OLIGOCENE STRATA, formerly grouped as Upper Eocene, are well seen in the Isle of Wight, and at Hordwell on the Hampshire coast. They constitute the *Fluvio-marine Series* of the Hampshire Basin, and are unknown elsewhere in Britain.

The *Headon Beds* mark the earliest stage in this Series, and consist of marls, variegated clays, occasional bands of limestone, and sands. The 'Headon Hill Sands,' which lie at the base, are now included with the Eocene strata, as their fossils show them to belong to the Barton Beds. The Headon Beds are from 150 to 200 feet thick, and they contain layers of fresh-water, estuarine, and marine origin. They are well shown at Headon Hill and Colwell Bay, and also in Whitecliff Bay in the Isle of Wight, and at Hordwell and Brockenhurst in Hampshire (see Fig. 70, p. 205).

The marine strata contain teeth of *Lamna*; there is a '*Venus*-bed' with *Cytherea incrassata*; and among other Mollusca there are *Ostrea flabellula*, *Voluta spinosa*, *Murex*, *Natica depressa*, &c. The brackish-water strata have yielded *Cerithium concavum*, *C. pseudo-cinctum*, *Neritina*, *Melanopsis subfusiformis*, *Potamomya plana*, &c.; and the fresh-water rocks contain *Paludina lenta*, *Planorbis euomphalus*, *Limnæa longiscata*, *Cyrena pulchra*, *Unio Solandri*, &c., besides land-shells, such as *Helix occlusa*, and vegetable remains, including *Chara Wrightii*.

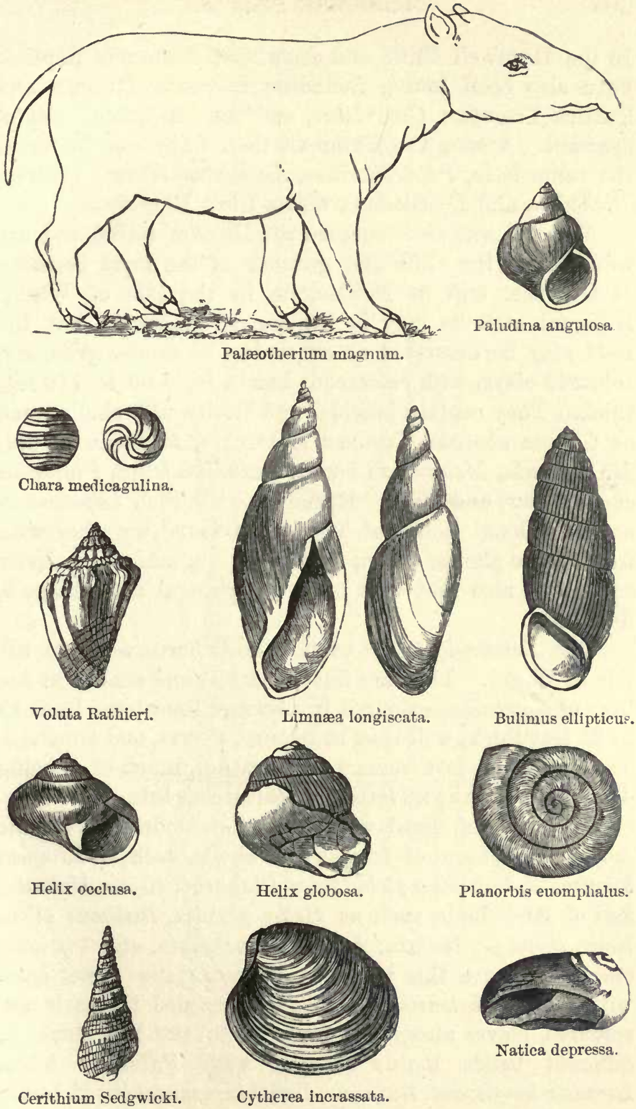


Fig. 69.—Group of Oligocene Fossils.

In the Hordwell Cliffs and elsewhere, numerous Reptiles have also been found, including Serpents *Paleryx* and Turtles *Trionyx*; *Crocodilus*, and the 'Alligator' *Diplocynodon*. Among the Mammals there have been found in the same beds, *Palæotherium*, *Anthracotherium*, *Viverra*, *Dichodon*, and *Hyænodon*; also a Bird, *Macrornis*.

The *Osborne Beds* succeed the Headon series, and are well seen in the cliffs and grounds of the royal demesne at Osborne, and at Nettlestone in the Isle of Wight. Different sections vary in lithological character, but the beds may be described as consisting of sands, grits, and coloured clays, with calcareous bands, from 80 to 110 feet thick. They contain brackish and fresh-water shells, such as *Cyrena obovata*, *Limnæa longiscata*, *Melania costata*, *M. excavata*, *Melanopsis brevis*, *Paludina lenta*, *Planorbis euomphalus*, and *Unio*. Remains of the Fish *Lepidosteus* and occasional bones of Turtle are found, together with fresh-water plants, *Chara Lyelli*, &c. A land-shell, *Helix occlusa*, is also met with; but the general assemblage is fluviatile.

The *Bembridge Beds* overlie the Osborne series in the Isle of Wight. They are fluvio-marine, and consist at the base of soft cream-coloured fresh-water limestone, from 15 to 25 feet thick, well seen at Sconce, Cowes, and Binstead. The limestone is a remarkable stratum, much of it being described as a true travertine or calcareous tufa, containing, or consisting of, hard white limestone-nodules, with the remains of *Chara*, of fresh-water shells, such as *Limnæa longiscata*, *Paludina globuloides*, *Planorbis discus*, *Melania*, and of land-shells, such as *Helix globosa*, *Bulimus ellipticus*, *Pupa perdentata*, *Achatina costellata*, and *Cyclotus cinctus*. Above this bed is a characteristic oyster-band with *Ostrea vectensis*, and this is succeeded by marls and coloured clays, altogether from 70 to 120 feet thick, in different bands highly charged with *Paludina lenta*, *Limnæa longiscata*, *Bulimus*, *Cerithium mutabile*, *Melania*, *Unio*, *Cyrena pulchra*, *C. semistriata*, *C. obovata*, and

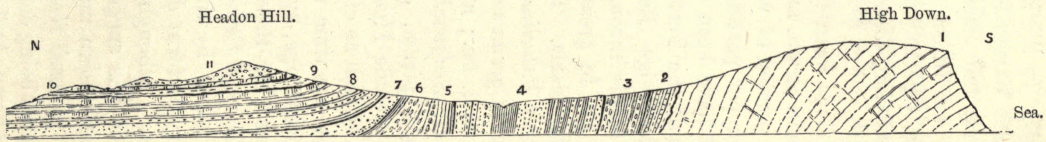


FIG. 70.—SECTION ACROSS THE ISLE OF WIGHT FROM HIGH DOWN TO HEADON HILL, SHOWING THE ARRANGEMENT OF THE STRATA IN ALUM BAY. BY H. W. BRISTOW, F.R.S.

6. Barton Beds.	11. Gravel (Post-pliocene).
5. Bracklesham Beds.	10. Bembridge Beds.
4. Lower Bagshot Beds.	9. Osborne Beds.
3. London Clay.	8. Headon Beds.
2. Woolwich and Reading Beds.	7. Headon Hill Sands.
1, Chalk.	

other fresh- and brackish-water shells. In the Bembridge Beds there have also been found the Mammals *Anoplotherium, Chœropotamus, Hyopotamus,* and *Palæotherium magnum* (Fig. 69). There is also an Insect Bed that contains a variety of Insect-remains, together with Crustacea. There are likewise Plants, including *Chara medicagulina.*

The *Hamstead* (or *Hempstead*) *Beds* form the uppermost portion of the British Oligocene strata, and consist mainly of coloured clays, the lower portion of which is of lacustrine and estuarine origin, the upper portion marine. They are about 260 feet thick, and have been shown by Mr. C. Reid to extend over about half the Tertiary basin in the Isle of Wight. The Bembridge Beds below pass gradually into them, and the fossils throughout the lower part of the Hamstead series are in great measure identical with those of the Bembridge marls. The Hamstead Beds in the lower part contain *Paludina lenta* in profusion, *Planorbis obtusus, Limnæa, Cyrena semistriata, Unio Gibbsi, Melania, Cyclas Bristovii,* &c.; and in the upper part, *Cerithium plicatum, C. Sedgwicki, Voluta Rathieri, Ostrea callifera, Corbula pisum,* &c. The Mammals, by no means abundant, include *Hyopotamus*; and bones of Turtle and Crocodile, as well as of the Bird *Ptenornis,* occur in these strata. At one time the Hamstead Beds were regarded as of Miocene age, by Lyell, on account of some of the Plant-remains; but these are now considered to link them with the Oligocene Series.

The temperature of the sea, judged by the marine Mollusca, appears to have been very uniform during the deposition of the Oligocene strata. Athough nowhere found in the London Basin, Mr. Reid has suggested that their presence beneath the German Ocean may be indicated by the occurrence of Amber (a fossil resin) in the Pliocene Beds of Norfolk—such material being derived from submarine extensions of the well-known Amber-bearing beds of the Baltic shores of Prussia. If the Oligocene strata formerly extended over the area of the London Basin, all traces of them have been destroyed by denudation. A long interval elapsed before the Pliocene deposits were laid down, an interval elsewhere represented by the formations of Miocene age. In our country this was an interval of disturbance and denudation, but we have no deposits that can be definitely assigned to the period.

CHAPTER XVIII.

PLIOCENE STRATA.

The Pliocene Strata belong to the upper part of the Tertiary system, and in England are represented chiefly by the various subdivisions of the Crag of Suffolk and Norfolk. Resting, as these strata generally do, on an eroded surface of London Clay, or Chalk, their lower boundary is sufficiently clear; but the same is not the case with the upper limit of the Crag series, about which diversities of opinion exist, because in some places it has been found difficult to separate the deposits of Pliocene age from those of the overlying Glacial Drift. The whole series of Crags is probably from about 120 to 250 feet thick, but the beds make no decided mark on the physical geography of the country, though important from other points of view.

The *Coralline Crag* lies on the London Clay in Suffolk, and is found mainly between the River Stour and Aldborough. There are many pits in the neighbourhood of Orford. This Crag is not more than 70 or 80 feet in thickness. It consists in places largely of Polyzoa (formerly called Corallines, whence the name, Coralline Crag), and elsewhere, in great part, of sand and marly beds, with broken and entire shells, fragments of Echini, &c. More than half the species of Mollusca are now living, and they indicate a somewhat warmer climate than that of the British Isles at the present time, and a moderately shallow sea.

The Coralline Crag contains a few Brachiopods, notably fine examples of *Terebratula grandis*, also *Terebratulina caput-serpentis*. Of the Lamellibranchs, the more abundant are *Pecten opercularis*, *Cyprina islandica*, *C. rustica*, *Cardita senilis*, *Astarte Omalii*, *Lucina borealis*, while *Glycimeris angusta* and *Pholadomya Hesterna* are also found. Among Gasteropods, *Turritella incrassata* is

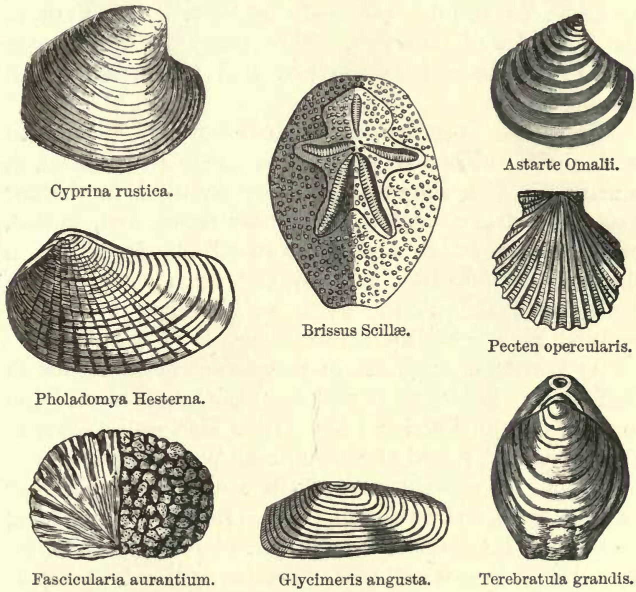


FIG. 71.—GROUP OF CORALLINE CRAG FOSSILS.

conspicuous, and many specimens of *Fusus*, *Natica*, *Calyptræa*, *Scalaria*, &c., may be obtained.

Patches of Crag have been found on the North Downs at Paddlesworth, near Folkestone, and at Lenham, near Maidstone. The preservation of these is owing to the material having filled 'pipes' in the Chalk, similar to those represented in Figs. 103 and 112. The fossils appear in the form of casts and moulds in ironstone, and we owe the first description of them to Professor Prestwich, who has termed the strata the *Lenham Beds*. According to Mr. C. Reid, the fauna, though differing in some measure from that of the Coralline Crag, is sufficiently near to indicate only different conditions in the marine area. A noteworthy form in the Lenham Beds is *Arca diluvii*.

Another remarkable discovery of Crag, first determined by S. V. Wood, jun., was made in 1882, at St. Erth, in the far west of Cornwall. Here many Mollusca, some common to both Coralline and Red Crags, have been obtained.

The *Red Crag* is a ferruginous sand, often crowded with shells entire and broken, and irregularly bedded, in a manner which shows that it was deposited in shallow seas, with strong tidal currents near shore, and, indeed, partly between high and low water-lines. It attains a thickness of from 40 to 150 feet, and when obtained at a depth below the surface, as in well-borings, it is often greenish-grey or bluish-grey in colour.

At Walton-on-the-Naze in Essex, and at Felixstow in Suffolk, the Red Crag is well seen in the sea-cliffs, lying directly on the London Clay. It is also well shown at Bawdsey, Butley, and at Sutton, near Woodbridge.

Among its characteristic shells are *Trophon antiquus* var. *contraria*, and we also find *Voluta Lamberti*, *Cassidaria bicatenata*, *Buccinum Dalei*, *Purpura lapillus*, *Natica*, &c. Lamellibranchs are still more common, such as *Pecten opercularis*, *Pectunculus glycimeris*, *Cardium edule*, *Tellina obliqua*, *Mactra*, *Mytilus edulis*, &c. Some of the shells have been derived from the waste of the Coralline Crag.

At the base of the Coralline Crag, and more commonly at the base of the Red Crag, when that formation rests directly on the London Clay, there is a 'nodule-bed' or stratum full of phosphatic nodules and phosphatised fossils, known as the Coprolite-bed. In it are found many Sharks' teeth, *Carcharodon megalodon*, vertebræ of Fishes, and many ear-bones and occasional vertebræ and other bones of Whales. The Sharks' teeth, such as *Lamna obliquus*,

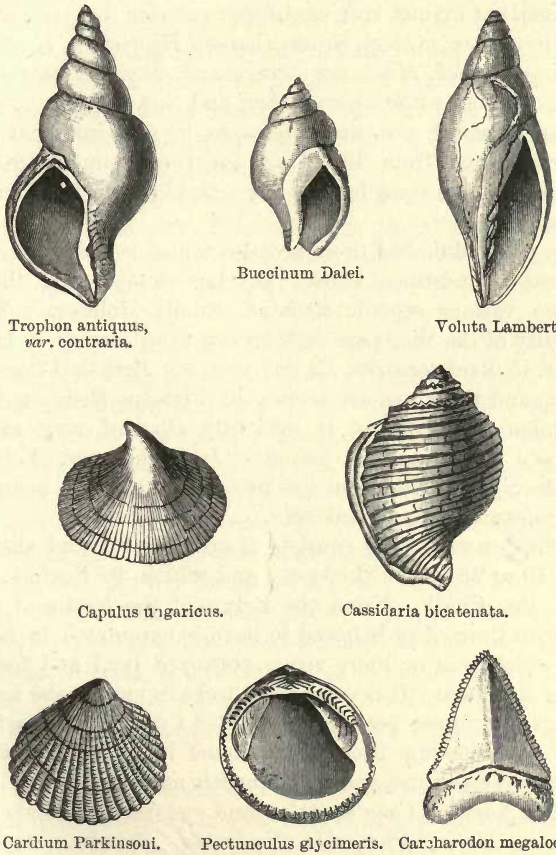


Fig. 72.—Group of Red Crag Fossils.

and other forms, have been derived from the London Clay, or even from the Chalk ; nevertheless, some, like *Carcharodon megalodon*, may belong to the Pliocene period ; while the Whales' bones are much water-worn, and have a more ancient appearance than that of the ordinary fossils of the Crag. There are also found the bones and teeth of land Mammals of extinct species, *Castor veterior* (beaver), *Cervus dicranoceros* (deer), *Equus* (horse), *Hipparion*, *Hyæna*, *Felis pardoides*, *Mastodon arvernensis*, *Elephas meridionalis*, *Rhinoceros Schleiermacheri* and *Sus*.

So plentiful are these phosphatic remains, that to separate them from the Crag, for the manufacture of manure, at one time formed a profitable branch of commerce.

In the nodule-bed there are also found rounded stones of brown sandstone, known as 'box-stones,' and these enclose various organic remains, chiefly Mollusca. The majority of the shells are well-known Crag forms; in fact, as Mr. C. Reid remarks, all but two are British Pliocene forms, and these two are known in Pliocene Beds on the continent. The fauna is evidently that of very early Pliocene times, and it includes *Isocardia cor*, *Voluta Lamberti*, &c. Attention was first drawn to these nodules by Professor E. Ray Lankester.

The *Norwich Crag* consists of sand, gravel, and shells, from 10 to 25 feet in thickness, and which, in Norfolk, lie upon the Chalk. From the nature of the fossils of the Norwich Crag, it is believed to have accumulated in bays into which one or more rivers conveyed land and fresh-water Mollusca. It is considered to be in part of the same age as the upper portion of the Red Crag, and in part of later date, having been accumulated in an area at first somewhat estuarine, and subsequently more purely marine.

The Norwich Crag contains land and fresh-water shells, such as *Helix*, *Planorbis*, *Hydrobia*, *Paludina media*, *Pupa*, *Limnæa*, *Corbicula fluminalis*, &c., most of which are of living species. The more abundant fossils are, *Tellina obliqua*, *T. prætenuis*, *Cardium edule*, *Mactra ovalis*, *Mya arenaria*, *Littorina littorea*, *Purpura lapillus*, *Cerithium tricinctum*, *Turritella terebra*, *Natica catena*, &c.

Besides these, there are found in it the bones of *Mastodon arvernensis*, *Elephas antiquus*, *Equus*, *Gazella anglica*, *Cervus ardeus*, *Trogontherium*, *Lutra*, &c. Most of these remains are found at or near the base of the deposit, in a 'stone-bed' formed chiefly of partially rolled flints. This accumulation is similar in character to that now in process of formation on the Norfolk coast near Sherringham, where the sea is encroaching over a platform of Chalk, and forming a deposit of rough flints and sand.

The *Chillesford Clay* and *Sand* are generally considered to form part of the Norwich Crag Series of strata. At Chillesford, near Orford, these beds overlie Red Crag, the upper part of which is considered to represent the lower portion of the Norwich Crag. They contain *Astarte borealis* and other Norwich Crag shells. In the Norwich district, the Crag contains seams of laminated clay, which occur at different horizons in the Norwich Crag Series; and the mass of the shelly Crag, so well seen at Bramerton, Whitlingham, and Thorpe, is overlain by pebbly gravels that occasionally contain organic remains. These gravels have yielded casts of Mollusca at Thorpe, near Norwich, and they have been designated, by Messrs. S. V. Wood and F. W. Harmer, the *Bure Valley Beds*, from their development in the Bure Valley at Belaugh and Wroxham. They are characterised by the presence of *Tellina balthica*, a shell not found in earlier stages of the Crag. They are well seen in the low cliffs at Weybourn on the Norfolk coast, and underlie the Forest Bed Series at Sherringham.

The *Westleton Beds* of Professor Prestwich have to some extent been correlated with the Bure Valley Beds, but they consist of pebbly gravel, which, at Westleton, near Dunwich, occupies a higher horizon than the Pliocene strata, and may more properly be included with the Pleistocene Drift.

Younger than the Norwich Crag Series there are certain other minor deposits, portions of which are scattered here and there throughout England. One of the most remarkable, the '*Cromer Forest Bed*,' lies underneath the Glacial deposits on the foreshore, from Kessingland, near Lowestoft, to Cromer and Sherringham, in Norfolk. It consists of dark sandy clay, coarse gravel, and bands of clay and gravel, with marine and fresh-water shells and fragments of wood. As described by Mr. C. Reid, this formation, where most complete, consists of an upper and lower fresh-water bed, and an intermediate estuarine deposit. Most interest has attached to the estuarine portion, which contains so much drift wood and so many old stumps of trees, that it was held to be an old land-surface by Lyell, John Gunn, and others. Remains of Birch, Alder, Oak, Yew, Scotch Fir, and Spruce are abundant, and many other plants have been obtained, notably the Water Chestnut, *Trapa natans*. The Mammals include *Elephas meridionalis*, *E. antiquus*, *Rhinoceros etruscus*, *Hippopotamus*, *Trogontherium* (Beaver), many species of *Cervus*, also *Hyæna*, *Ursus spelæus*, &c.

The upper surface of the estuarine beds is often penetrated by small roots, and hence the term 'rootlet-bed' has been applied to it. Hollows occur here and there, as at Runton, containing peaty deposits (upper fresh-water bed) with fresh-water shells and small bones of Mammalia.

Remains of *Elephas meridionalis* have been found at Dewlish, about six miles north-east of Dorchester; and the deposit in which they occur is probably a relic of late Pliocene times.

The physical conditions attending the Pliocene deposits point to a submergence of much of the south of England, and indicate that there was free connection between the German Ocean and more southern seas. In the east of England cliffs of London Clay and Chalk bordered the Crag seas. As the Red Crag was deposited the marine areas to the south became disconnected, and our Crag sea was open only to the waters of the Arctic regions. Cooler conditions are successively indicated in the later stages of the Crag. Finally, by further physical change, this area became upraised, and the fluviatile and estuarine conditions of the Cromer Forest Bed set in—being the deposits, in part, of a great river system connected with the Rhine drainage. Thus it is that in the Forest Bed, as Mr. Reid states, we have evidence of a southern land-fauna contemporaneous with an arctic marine fauna. The special importance of the Cromer Forest Bed is, that it exhibits a fragment of the vegetation and fauna of the last pre-glacial epoch, at a time when England was united to the Continent, and when a flora and fauna, in part new, migrated across the intervening plain into our area.

An arctic fresh-water bed that occurs above the Cromer Forest Bed has yielded remains of the Arctic Birch and Willow, *Betula nana* and *Salix polaris*. This bed marks the first stage of the succeeding Pleistocene period, in which Glacial phenomena played so prominent and important a part.

CHAPTER XIX.

PLEISTOCENE GLACIAL EPOCH.—EXISTING GLACIER REGIONS.

I HAVE now to describe a remarkable episode in Post-Tertiary times, known as the *Glacial epoch*, which is certainly later than the latest beds of the Crag, and later than the 'Forest Bed' of Cromer. The effects of local mountain glaciers, and of far broader sheets of glacier-ice that descended from the mountains and overspread great plains and hilly undulations, may be unmistakably traced over large parts of the northern and southern hemispheres; and without going into all the minutiæ of the subject it will be desirable to describe the history of that period, as it affects the scenery of Britain, with something like detail.

The first thing to be done is to explain what a glacier is. The higher mountain-ranges of the Alps are more or less covered by snow and glaciers. The highest mountain, Mont Blanc, rises more than 15,000 feet above the sea, and there are many other mountains in this great chain which approach that height, ranging from 10,000 to 15,000 feet high. The mean limit of perpetual snow upon the Alps is about 8,500 feet above the level of the sea. Above that line, speaking generally, the country is to a great extent covered with snow, excepting where the tall cliffs are too steep to hold it, or on those sides of even high valleys that face the southern sun. In the higher regions it gathers on the mountain slopes, and in the large cirques or rocky recesses, which, like vast amphitheatres, are characteristic of all true mountain groups. By force of gravity, and the alternate melting and regelation of the molecules of ice, especially in summer, the gathered snow presses downwards into the main valleys, where, chiefly in consequence of the immense pressure exerted by the vertical weight and onward impulse of the accumulated mass, the snow year after year is converted into moving ice. Still accumulating, by degrees this ice slides lower down the valleys, and is often protruded in great tongues far below the limits of perpetual snow; for some Swiss glaciers descend as low as from *three* to *four* thousand feet or thereabouts above the level of the sea.

A glacier slides more or less rapidly according to the mass of ice that occupies the valley, and to the greater or less inclination of the slope, for in these respects it behaves very like a river: representing, in fact, the snow-drainage of a large tract of country. Like a river also when the valley expands in width, so does the glacier broaden to meet the mountain sides; and should an extra steep descent occur in its channel, as in the glacier of the Rhone, the ice becomes troubled and shattered, like a silent frozen cataract, to re-unite below in a more tranquil sheet. So also in the valley of Hinter Rhine, above the source of the river, a tall cliff bounds the eastern side of the Rhine glacier, above which another large ice-flow presses to the edge of the precipice, whence in summer, constant avalanches, now here, now there, fall with a sheer descent and a recurrent roar like that of a great waterfall.

All glaciers are traversed by cracks termed crevasses. Now the mountain peaks that rise above the surface of a glacier are in places 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. Hence large and small masses of rock that are severed by atmospheric disintegration constantly fall from the slopes on to the ice at the margin of the moving glacier, and travel upon its surface in long continuous lines; for the motion of a glacier is so slow, that the stones that fall upon its surface are sufficiently numerous to keep up a continuous line of blocks, earth, and gravel, often of great width. In like manner if an island-like boss of rock rises through the ice in the middle of a glacier, a line of stony débris travels on the surface of the glacier from the lower end of the island, which, often buried in the winter's snow, becomes again exposed during the heat of summer. These stones, when two glaciers combine to form one stream of ice, as in the lower glacier of the Aar, meet at the V-shaped angle of junction, and form one grand course of material running down the centre of the glacier (Fig. 73). Such lines of débris, whether at the sides or in the middle of a glacier, are termed *moraines* (*lateral* or *medial* as the case may be). At length all this material that has not fallen into crevasses travels on, and, when the ice melts, it is finally shot into the valley at the end of the glacier, forming large mounds, known as *terminal moraines*.

All glacier ice, even in the depth of winter in Arctic regions, is said to be at a temperature of about 32° Fahr., that is to say, just about the melting point, excepting near the surface, as far as the cold atmospheric temperature can penetrate. This, it is said, is rarely more than eight or ten feet. Therefore, it is a common statement that, beneath every glacier, water is constantly flowing, caused by the melting of the ice below all the year round, and also by the summer heat on the surface of the glacier, and in some cases, to a less degree, by springs that rise in the rocks below the ice. In parts of some glaciers where crevasses are not numerous, we frequently find large temporary brooks, which generally disappear with the frost at night; but long before we reach their lower end, the surface water has found its way to the bottom of the ice.

The water that runs from the end of a glacier very often emerges from an ice-cavern as a ready-made muddy river, charged with the *flour of rocks*, produced in great part by the grinding power of the glacier and its embedded stones moving over its rocky floor; and the stream moves or carries away the moraine material that the glacier deposits at its lower end, in some cases almost as fast at it is formed. We might rather say, as slowly as it is formed, because day after day we may see scarcely any difference in the features of certain moraines, though, when being worked upon by water, all stones of moderate size, that have been shed from the ice, are in the long run apt to be carried down the valley by the ever-changing streams that flow from the ends of glaciers. In some cases, however, where glaciers have retreated, it happens that both terminal and lateral moraines have been so well preserved from destruction, that they form long enduring features in the scenery.

Something remains to be said about moraine-stones before we describe the glacial phenomena of our own island. When an immense weight of glacier-ice, in some cases hundreds, or in Arctic and Antarctic regions even thousands of feet in thickness, passes over solid rocks, by the pressure of the moving mass, the rocks over which it slides become smooth and polished—not always flatly, but often in flowing lines, presenting a largely mammillated surface. Such smoothed and rounded surfaces are known as *roches moutonnées*. Furthermore, the stones of the surface-moraines frequently fall into fractures called crevasses, and the small débris and finely powdered rocks that are strewn over the glacier are borne into these crevasses by the water that flows upon the surface, and much of this matter finds its way to the bottom of the ice (Fig. 73). The bottom of a glacier, therefore, is not simple bare ice, but between the ice and the rock over which it flows there are blocks of stone imprisoned, and fine siliceous and often felspathic débris (chiefly worn from the floor itself), which may be likened to emery powder. The result is that, let the rock be ever so hard, it is in places rendered almost as smooth as polished agate, and this surface is also finely striated and grooved by the débris that, imprisoned

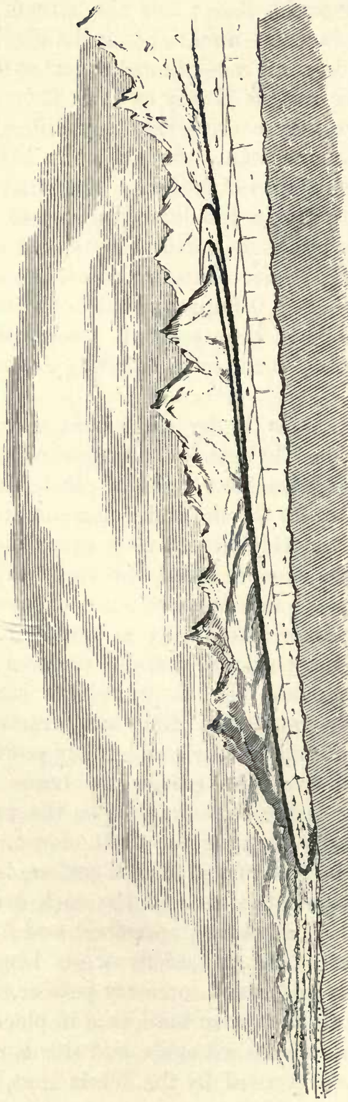


FIG. 73.—IMAGINARY SECTION OF A SWISS GLACIER.

Showing Moraines, Crevasses, and the undulating form of the ground underneath (small *Roches moutonnees*).

between the ice and the rocky floor, is pressed along in the direction of the flow of the ice. Thus also by degrees deep furrows are sometimes cut in the rocks.

Moreover, the stones that are imprisoned between the ice and the rocky floor not only groove that floor, but in turn they also get scratched by the harder asperities of the rocks over which they are forced; and we find that certain of the stones of moraines are covered with straight *scratches* or *striæ,* often crossing each other irregularly. Hence we can tell, independently of the forms of the heaps, whether such and such a mass is a moraine or not, and whether certain stones have been acted on by glacier-ice (see Fig. 74).

These indications of the rounding, smoothing, scratching, and grooving of rocks, in lines coincident with the direction of the flow of glaciers, together with moraine heaps, erratic blocks, and scratched stones, are so characteristic of glaciers, that we are able to establish the important fact that the Swiss glaciers were once of far larger dimensions than they now are, and have gradually retreated to their present limits. The signs of gigantic vanished glaciers constantly strike the practised eye, and are indeed frequently as fresh as if the glacier had scarcely left the rocks before the existing vegetation began to grow upon their surfaces.

Those who have read the descriptions of navigators will be aware that in Greenland the average snow-line, as a whole, descends lower and lower as we go northward, till at length the whole interior of the country becomes covered by one snowfield, which, pressing seaward from the interior, gives birth to a prodigious number of large glaciers, many of which protrude far into the Fiords, while elsewhere the ice-sheet less thick descends directly into the sea from the mountains on either side. In other cases, the glacier-ice crowns the cliffs for miles, and, breaking off in masses, falls in cataracts of small-shivered icebergs into the sea, grinding and smoothing the land as they descend. Again when broader valleys open out towards the sea, then prodigious

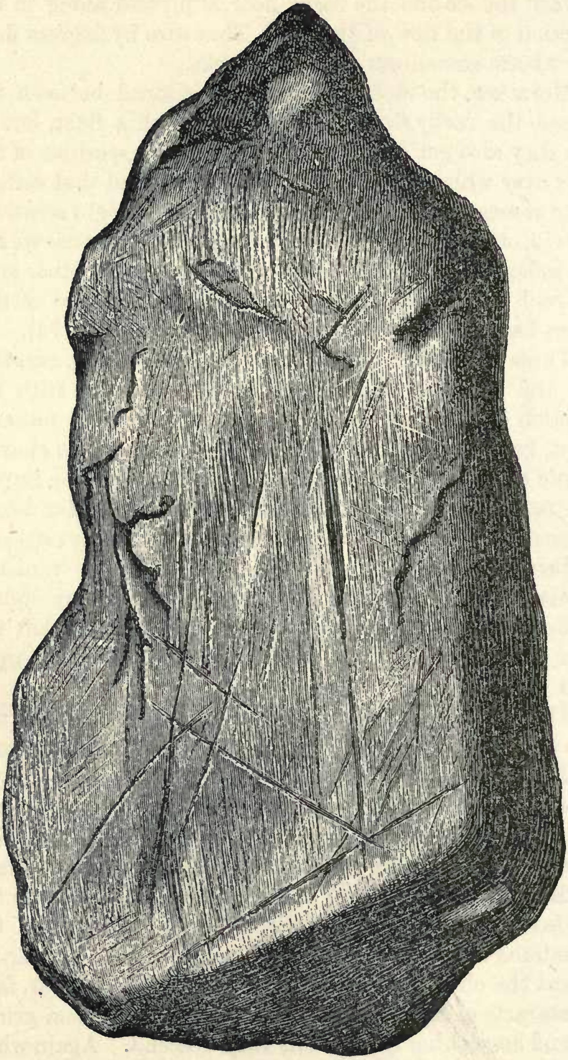


FIG. 74.—ICE-SCRATCHED STONE. (J. G.)

glaciers may push their way out far beyond the shore. These are in some cases 12 or 20 miles across at their ends, while the great Humboldt glacier, 60 miles across, ends in a cliff of ice in places 300 feet in height. One of these vast glaciers has been estimated to be at least 3,000 feet in thickness. Great masses of ice breaking away from their ends form icebergs, which, sometimes laden with moraine material, like that found on the glaciers of Switzerland, float out into the Greenland seas, and are carried south by a current in Baffin's Bay.

Along the shores also, when the sea freezes, the ice becomes attached to the coast. By-and-by, as summer comes on, the ice partly breaks away, leaving what is called an *ice-foot* still joined to the land. Vast quantities of débris during part of the year fall from the cliffs, and are lodged upon the ice-foot, and when it breaks off and floats away and melts, the rubbish is strewn about, and accumulates on the bottom of Baffin's Bay. In like manner the icebergs melt chiefly in Baffin's Bay, but sometimes they escape thence and melting in the seas of warmer climates, their stony freights get scattered abroad here and there over the bottom of the West Atlantic, which, therefore, must be dotted with erratic blocks and other débris borne from far northern regions. Icebergs often drift to the south of the parallel of New York, and they have been seen even off the Azores.

The same kinds of phenomena, on a still grander scale, are common in the Antarctic regions of Victoria Land. There the country may be said to be almost wholly covered by a sheet of glacier ice, which, protruding far seaward, rises in cliffs from 150 to 250 feet and more above the level of the sea. From this sheet great tabular bergs break off, occasionally bearing blocks of volcanic rocks. Sir James Ross estimated the thickness of the glacier-ice to be as much as 1,000 feet, but in many cases this is an under-estimate ; indeed, it is thought that in places the ice-cap must be 10,000 feet thick. This Antarctic continent is probably as large as or larger than Australia, and its surface must be ground and polished by the nearly universal glacier that radiates from its centre to the sea.

Having ascertained what are the signs by which glaciers may be known, and also the signs left by icebergs, I shall now show that a large part of the British Islands has been subjected to *glaciation*, or the action of glacier-ice.

CHAPTER XX.

PLEISTOCENE GLACIAL EPOCH.—OLDER BRITISH GLACIERS AND ICE-SHEETS.

THOSE who have closely observed the Highlands of Scotland and the mountains of Wales and Cumberland, may remember that, though the weather has had a powerful influence, rendering the mountains in places rugged, jagged, and cliffy, yet, notwithstanding this, in many places their general outlines are often remarkably rounded, flowing in great and small mammillated curves. When we examine the valleys and plains in detail, we also find the same mammillated appearances, or *roches moutonnées*, marked by the same kind of grooving and striation so characteristic of the rocks of Switzerland.

Considering all these things, geologists, led many years ago by Agassiz and Buckland, have by degrees come to the conclusion that large parts of the northern hemisphere were, during the 'Glacial period,' more or less covered, or nearly covered, with a coating of thick ice, in the same way that the greater parts of Greenland, Spitzbergen, and the whole of Victoria Land are covered at present. Britain formed part of this area, and, by the long-continued grinding power of great glaciers nearly universal over the northern half of our country and Wales, the whole surface became *moulded by ice*. The relics of this action still remain strongly impressed on this country to attest its former power, and the same kind of phenomena are equally striking in Ireland.

It might be unsafe to form this conclusion merely by an examination of such a small tract of country as the British Islands, but in the great Scandinavian chain, in the northern half of Europe generally, and in North America, we find that similar phenomena are common ; for when the soil or the superficial covering of other débris is removed, we discover over large areas, that the solid rock is smoothed and polished, and covered with grooves and striations, similar to those of which we have experience among the glaciers of the Alps. No power on earth, of a natural kind, produces these indications except moving ice, and therefore geologists are justified in attributing them, even on this great continental scale, to ice-action.

This conclusion is fortified by many other circumstances. Thus in the Alps there is evidence that the glaciers were formerly on a very much larger scale than at present. The proof lies not only in the polished and grooved rocks far removed from the actual glaciers of the present day, but also in numerous moraines on a scale so immense that the largest now forming in the Alps is of pigmy size when compared with them. The same kind of phenomena occur in the Altai Mountains, the Himalaya, the Caucasus, the Rocky Mountains, the Sierra Nevada and the Pyrenees of Spain, the mountains of Sweden and Norway, and in many other northern mountain chains or clusters, great or small, that have been critically examined. In the southern hemisphere, where mountain ranges are comparatively scarce, the same ancient extension of glaciers is prominent in New Zealand. Therefore there can be no doubt that at late periods of the world's history colder climates prevailed over large tracts of the earth's surface, generally, but not always, of extreme severity, for there were intermittent episodes of comparative warmth.

It is not very many years since a great difference in the geographical distribution of land and sea was regarded as a possible or even a probable cause of the occurrence of important changes of climate during Geological Time. In such a sketch as this it is needless to argue the question, at all events as regards this special glacial epoch, for the obvious reason that it is an established fact that during this epoch the great continents of the world, mountain chains and all, were distributed much as they are at present, with occasional minor variations in detail due to short local submergences. Neither is it worth while to discuss the explanation of variation of climate, being due to the sun with all its planets travelling through alternate hot and cold regions of space.

The day may come when both astronomers and geologists will be forced to allow that, in great cycles of geological time, changes have taken place in the position of the earth's axis of rotation, by gradual disturbances of what is called the crust of the earth; and, indeed, the phenomena of the vegetation of old geological epochs in formations as far north as land has been discovered, seem to point in that direction. There is, however, an astronomical cause of climatal change to which attention was called by Sir John Herschel, and which has been worked out with great skill by Dr. James Croll. It is that alternations of cold and warm or temperate climates, in the same latitudes, are in the first instance due to the varying eccentricity of the orbit of the earth; and that thereby winds and ocean-currents affecting climate have been modified.

Croll, moreover, set forth reasons for believing that there have been alternate glaciations of the northern and southern hemispheres; and that while the one is undergoing severe glaciation, the other is undergoing a comparatively warm climate.[1] Thus the Antarctic region is now undergoing a minor glacial epoch, the conditions not having reached the full intensity of cold.

It was when one of these cold periods affected the northern hemisphere, that great part of what is now the British Islands was almost entirely covered with ice. Probably during the period the tract was united with the

[1] *Climate and Time in their Geological Relations*, 1875.

Continent, and the average level of the land may then have been somewhat higher than at present, by elevation of the whole, and also because since the first appearance of British glaciers the land has suffered much degradation. Whether this was so or not, the mountains and much of the lowlands were long covered with a great coating of ice, probably as thick as that in the north of Greenland at the present day.

It is a self-evident proposition, that when cold began to increase sufficiently to produce glaciers in Britain, these in their infancy must have been first formed in the more elevated regions of the north, among the Highland mountains, where precipitation of snow was greatest. As the climate became more severe, such glaciers would spread from the upland glens in all directions, and by-and-by, as cold and precipitation became more and more intense, the whole mountain-land, like the interior of Greenland, was smothered in ice. Then a prodigious onflow of glacier-ice spread from the Highlands westwards into the Atlantic across the Outer Hebrides, and southwards into the North or Irish Channel along the ice-buried valleys of the Sound of Jura, Loch Fyne, and the Firth of Clyde. Passing over Bute and smothering and smoothing the Cumbraes, the glacier-ice was reinforced by the snows of Arran, and buried that 'craggy ocean pyramid,' Ailsa Craig. In the Outer Hebrides, according to Professor J. Geikie, the striæ range from SE. to NW., and the only points that escaped glaciation exceed the height of 1,600 feet.

Further south, being largely reinforced by tributary ice that descended from the Galloway mountains and all the high lands, the slopes of which, then filled with tributary ice, now send rivers into the Solway, the advancing mass invaded the area called the Irish Sea, where it was still further swelled by the glaciers that descended from the mountains of Cumberland. These facts are further confirmed by observations in the Isle of Man by the Rev. J. G. Cumming, who showed that the chief glacial striations in that island trend from NNE. to SSW., as if the ice that made them travelled from the high ground of Kirkcudbrightshire and the borders of the Solway Firth.

It is obvious that the whole of the mountains of Cumbria and Westmoreland must have been buried in ice during the period of extreme cold. According to Mr. J. G. Goodchild, the advancing ice must have risen to an elevation of over 2,400 feet above the present level of the sea. Though now somewhat ruined by time, the mammillated forms of the rocks proclaim it, and in the time that the glacier-ice attained its maximum, that ice, pressed on by ice coming from the north, must have passed southward into and far beyond Morecambe Bay. East of this mountain-land, between the rivers Kent and Lune, almost all the striations run in a south-westerly direction, while on all the high Fells on both sides of the Ribble, the prevailing direction of the striæ is either south or a few degrees west of south, as shown by Mr. R. H. Tiddeman. Such striations range from a few feet up to 1,375 feet above the sea.

One great fact taught by the study of these phenomena is, that the broad and thick ice-sheet, urged onward from the north, buried the whole of the region described, and all the ground to the east as far as the sea. Further, they show that the glacier, moulding itself to the shape of the country (after the manner of all glaciers), was pressed right onward with so much force, that the long northern slopes of the east and west valleys offered comparatively no more impediment to its forward march, than an occasional transverse bar of rock hinders the onward flow of a river. Occasionally there are striations that do not quite conform to the rule, and in some cases these were due to undercurrents in the ice in some of the deeper valleys, and at a later date to minor glaciers that got specialised in the valleys during the decline and disappearance of the ice-sheet.

At Liverpool, and on the opposite side of the Mersey, Mr. G. H. Morton observed on the Keuper Sandstone certain ice-grooves, trending to the south-east, and this direction is probably connected with the circumstance that when the northern ice-sheet reached the rising ground of Denbighshire and Flintshire, it was deflected to the right and left; and while one part flowed south-easterly across the plains and undulations of Cheshire, another part flowed south-westerly, and, scraping the coast hills of North Wales, overwhelmed Anglesey and the low ground of Lleyn that forms the north horn of Cardigan Bay.

In time, however, as the great glaciers advanced, and the cold increased and snow in North Wales became perennial, then glaciers began to be formed in the high valleys in the upper recesses of the mountains. As the climate and the precipitation of snow grew more severe, these glaciers must have waxed in size, till at length they filled all the valleys, and intruded on the plains and low undulating grounds beyond. How far south they extended from the mountains of Merionethshire may be questioned, but probably the ice-flow went far into South Wales. Evidences of glacial action occur near St. David's and on Ramsey Island, and they are met with in the Boulder-drift that is scattered over the low ground of Glamorganshire between Cardiff and Bridgend; but the facts point mainly to local ice-action, and the deposits may belong to a later glaciation. Neither is it possible to say how far these early glaciers of Snowdonia stretched across the broad undulations of Anglesey, for, if they did so, the marks that they made were afterwards entirely obliterated by the onward march of the great northern glacier which no doubt extended southward into St. George's Channel. Along the Menai Straits, Carboniferous rocks form the larger part of either shore, and the Straits may be considered simply as a long shallow valley, the bottom of which happens to lie beneath the level of the sea. The question thus arises—At what epoch and by what means was Anglesey separated from the mainland? The entire island may be looked upon as a gently undulating plain, the higher parts of which attain an average elevation of from 200 to 300 feet above the level of the sea. On the opposite side of the Straits, the same kind of low, undulating scenery prevails for several miles inland, with the same kind of minor north-east valleys.

The surface of the ground on both sides of the Straits is to a considerable extent composed of glacial drift, with erratic boulders large and small (from the north), and gravel, sand, and clay. From these any number of ice-scratched stones may be gathered from well-exposed sections, as, for example, in the coast-cliff of the Mount at Beaumaris, or elsewhere round the shores of Anglesey, or, inland, in occasional pits and cuttings on both sides of the Straits. Through these glacial accumulations the rocks of the country frequently appear, sometimes in barren tracts of considerable extent, sometimes in small isolated bosses of gneiss or grit, often covered with heath or furze, while the more fertile grounds of the whole of Anglesey consist chiefly of glacial detritus, with here and there small alluvial meadows by the sides of the streams. When freshly stripped of glacial débris, or even of a mere thin turfy soil, the underlying rocks are often found to be ice-smoothed and marked with glacial striæ, running generally in a south-westerly direction.

The last great movement of the rocks of Wales is certainly older than the Permian epoch, and, probably, like the mountains of Cumberland, very much older. There was plenty of time, therefore, in what is now Wales, long before the beginning of the great Glacial episode, for the more ordinary agents of denudation to have formed deep valleys, down which, when that episode began, the growing glaciers might gravitate, deepening their channels as they pressed forward, and mammillating and striating the rocks over which they slid. Thus the great original valleys of the mountains were by no means entirely scooped out, but merely modified by the glaciers.

For example, it happens in Wales that all the striations in the valley of Dolgelly and the estuary of the Mawddach, in Merionethshire, follow the south-westerly trend of the valley, the glacier that filled it when at its greatest being fed by the snows of the slopes of Cader Idris and Aran Mowddwy, and those of the tributary valleys that joined it from the north. From a central low watershed, near the sources of the Wnion, another branch pressed north-easterly into and far beyond the region now occupied by Bala lake.

The striated rocks exposed among the sands at low tide in the estuary of the Mawddach, and the islet-like heathy bosses of rock that stand out amid the marshy moss opposite Barmouth, are merely *roches moutonnées*, once buried deep beneath the glacier that pressed forward to join the great northern glacier that then to some extent filled Cardigan Bay.

In like manner all the western valleys of the Cambrian mountains of Merionethshire are marked by deep grooves and striations pointing more or less westward, according to the trend of the valleys.

The broad flat moors and rough hilly ground bounded by the splendid amphitheatre of scarped mountains formed by the Arenigs, the Manods, the Moelwyns, and other heights, were at the same time filled to the brim with deep accumulations of snow and ice, from which were discharged radiating currents of glaciers.

On the north-west slopes of the Snowdonian mountains, great glaciers poured their ice-streams down the valleys, deriving additional power by aid of the tributary ice-flows, the chief gathering grounds of which were the cliffy *cirques* on the western flanks of Carnedd Llewelyn and Carnedd Dafydd, which, with other mountains, formed one great nursery of the glaciers of Caernarvonshire, sending off ice-flows eastward to Capel Curig and the valley of the Conwy, and westward to where Bangor now stands and the Lavan sands.

None of these glaciers, at a certain epoch, quite reached the region now occupied by the Menai Straits, but escaping from the higher bounding-walls of their valleys, they spread out in the shape of broad fans on the north-western slopes of the minor hills that now overlook the Straits. This is partly proved by the northerly curve of the glacial striations at the mouth of the Pass of Llanberis, on the flatter area above the steep slopes of the slate-quarries by Llyn Peris and Llyn Padarn.

These striations point directly towards the mountains of Cumberland, from which, as already stated, a vast mass of ice flowed southward; and reinforced by the ice-streams that came from the mountains of Carrick in the south of Scotland, and from the basin of the Clyde, it overspread the region now occupied by the shallow sea of Morecambe, and the bays that lie between Cumberland and Anglesey, nowhere more than 30 fathoms deep.

In its onward course, this mighty glacier buried all the hills and rounded knolls of Great and Little Ormes Head, which are still on a large scale so strikingly *moutonné*, and pressing along the slopes of Llanfairfechan and across the lower end of the valley of the Ogwen, it marked its track by long, slightly inclined terraces, somewhat faintly shown, but still clear to the experienced eye when looked for from the shores of Beaumaris. Beyond this the glacier continued its course across Lleyn, and onward to the region now occupied by St. George's Channel.

So great were the size and power of this ice-flow, that it hindered the glaciers of Llanberis and Nant Ffrancon from encroaching on the territory of Anglesey, and they simply joined the larger glacier as minor tributary ice-streams. For this reason it happens that the glacial striations of Anglesey do not point, as we might at first expect, towards the old glacier-valleys of Snowdonia that open on the Straits, but run at right angles to the courses of these comparatively minor glaciers.

If we now turn to the rocks that form the banks of

Menai Straits, we find that they chiefly consist of nearly flat-lying Carboniferous strata, and looking at the disposition of these beds, there is no reason to doubt that from end to end they once filled the whole of the region now occupied by the Straits. The larger part of this region, as it now exists, is of Carboniferous Limestone age; but it by no means consists entirely of solid limestone. On the contrary, numerous bands of shale and friable sandstones and conglomerates are intermingled with the limestones, together with beds of soft red marl. On the coast opposite Caernarvon, the low cliffs are entirely formed of red marl overlying the limestone; and on the Caernarvonshire coast, for three miles north of the town, also overlying the limestone, there are soft beds of Coal-measures.

In Anglesey, from three to four miles north-west of the Straits, lies the valley of Malldraeth Marsh, the rocks of which also consist of Carboniferous and Permian strata; and this valley, nine miles in length, runs almost exactly parallel to the valley of the Menai Straits. At its north-eastern end, there are deep glacial striations on the Millstone Grit, running straight down the shallow valley towards Caernarvon Bay.

Considering that the south-westerly trend of each of these valleys and of others of minor note corresponds with the general direction of the glacial striations of Anglesey, and therefore with the onward course of the great glacier that produced them, I have been led to the conclusion that both of the shallow valleys were scooped out in comparatively soft rocks by the grinding power of the vast glacier coming from the north-east. Finally, when the climate ameliorated, and the glacier disappeared, the sea flowed in where part of the glacier had been, and thus it was that Anglesey was separated from the mainland and first became an island.[1] The islets in the narrower and shallower part of the Straits at the Menai and Tubular

[1] Ramsay, 'How Anglesey became an Island,' *Quart. Journ. Geol. Soc.*, vol. xxxii. p. 116.

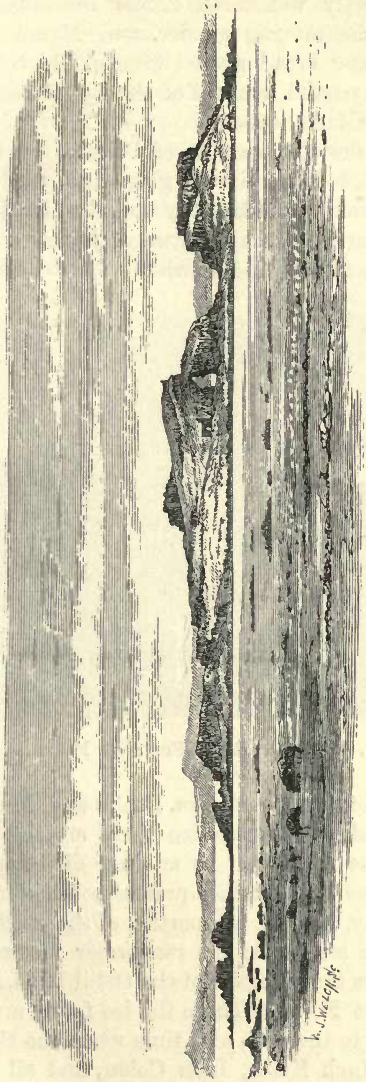


Fig. 75.—Fidra Island, North Berwick, Firth of Forth.

bridges are merely weathered *roches moutonnées*, once overridden by the moving glacier, and Menai Strait is merely a long and broad glacial groove, which was first laid bare by the partial removal of the Boulder-beds, after the close of the Glacial epoch.

Turning to the eastern side of Britain, we find that during the period of maximum glaciation, while all the Highland mountains were literally buried in ice, this great glacial sheet, partly flowing eastward, joined a vast ice-sheet coming westerly and southerly from Scandinavia.

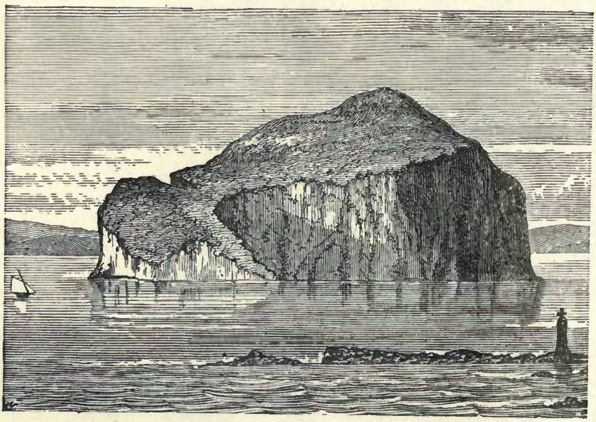


Fig. 76.—Bass Rock, Firth of Forth.

The evidence obtained by Messrs. Peach and Horne in the Shetland Isles shows that the ice there crossed from the North Sea to the Atlantic. In another direction a thick sheet of the same Highland ice pressed southward into the valley of the Tay, where a low portion of the glacier passed eastward to the sea, while the remainder pressed up the slopes and across the summits of the Ochil Hills, and on to the valley of the Forth. There the ice found a vent for a further outflow to the east, at a time when the Bass Rock, Fidra Island, Inch Keith, Inch Colon, and all the other beautiful islands of the Firth of Forth, lay as mere *roches moutonnées*, buried so deep under glacier-ice that it overflowed the eastern part of the Lammermuirs and spread southward into Northumberland. Some of these islands still retain their ice-worn surfaces, while others, such as the Bass and Fidra, have become scarred and cliffy by the action of the weather and the sea (Figs. 75 and 76). All the southern Highlands, from Fast Castle on the east to Wigtonshire on the west coast, were also covered with glacier-ice, together with Northumberland, Durham, and the beautiful dales of Yorkshire, scooped out of the Carboniferous rocks. Cumberland, too, was buried in ice, part of which arose from its own glaciers; and from this region the ice crossed the vale of Eden and over the hills beyond, carrying detritus to the eastern side of England.

CHAPTER XXI.

PLEISTOCENE GLACIAL EPOCH.—GLACIAL DRIFT.

MUCH of the *Boulder-clay* is known as '*Till*' in Scotland and elsewhere; and it was only by slow degrees that geologists became reconciled to the idea that this Till is nothing but moraine material on a vast scale, formed by those old glaciers that once covered the northern part of our country.

The general result has been that to the north of the Bristol Channel and of Gloucestershire the regions of Britain have literally been *moulded by ice*, that is to say, the country in many parts was so much ground by glacier-action, on a continental scale, that though in later times it has been more or less scarred by weather, enough remains of the effects to indicate the greatness of the power of moving ice. This ice incorporated in its mass or pushed onwards the rubble, loose detritus, or weathered material that occurred over the surface of the land after long-continued atmospheric action. Suddenly strip Greenland of its ice-sheet, and it will present a picture something like the greater part of Britain immediately after the close of the Glacial period.

During the time that these results were being produced by glacial action, there were occasional important oscillations in temperature, so that the ice sometimes increased and sometimes diminished, and land animals that lived habitually outside the great glacier limits, at intervals wandered north or retired south with the retreating or advancing ice.

Evidence in support of these views is given not only by the Till or Boulder-clay, but by the erratic stones and large blocks of granite, gneiss, felspathic traps, Carboniferous Limestone, &c., scattered over the west and east coasts and the central counties of England. Boulders of Shap granite from Cumberland are common in Staffordshire, and even in the valley of the Severn, about twelve miles north of Cheltenham, and they have also been borne across the central watershed of the north into the plains of Yorkshire, near Darlington, and further south on the banks of the Humber. This distribution of erratic blocks, on the east of England, throws much light on the subject of the motion of large sheets of glacier-ice, although we must bear in mind the possibility of blocks being moved in one direction at an early stage of the Glacial period, and being subsequently transported elsewhere.

In Scotland the Glacial Drifts are of a more mixed and variable nature than those we find spread over such large areas in England, especially in the eastern counties. The Boulder-clay in the north merges into an earthy drift and lies in irregular patches over the country, together with sands and gravels. Towards the hills, along the higher courses of the valleys, it often lies in long lines, called 'drums.' In some parts, as in Aberdeenshire, derived Crag Shells have been found, as in the 'Middle Glacial' Sands of East Anglia. Again, in Elgin there are transported masses of Rhætic Beds, as at Linksfield, and of Lias; while the 'Blackpots' clay, worked near Banff, is described as a boulder of Oxford Clay.

In many parts of Northumberland, when the Till has been removed in the process of quarrying, the surfaces of the Carboniferous Limestone are found to be ice-polished and grooved, the striations point from 10° to 15° south of east, in the direction, in fact, of the onward march of the vast glacier before described. The stones in the Till are scratched, and consist of Carboniferous Limestone and other materials derived from the northern hills. Some of the boulders are from one to two yards in diameter, and the beach-like sands and gravels that overlie the Till are charged with large blocks of limestone and porphyrite at the base, and many broken sea-shells. In places these sands are strangely contorted, as if they had been disturbed and pushed on by moving ice.

At Sunderland, about a mile north of the harbour light, there is a section of Boulder-clay lying on the Magnesian Limestone. The surface of this rock has been polished by glacier-ice, and the striations trend very nearly from north-east to south-west. The overlying clay has the character of genuine Till, and the change in the

Fig. 77.—Section at Sunderland.

4. Finely laminated clay.
3. Sand and loamy beds with scratched stones, rare.
2. Stiff brown Till with blocks and scratched stones. The largest are of Carboniferous Limestone and Magnesian Limestone, from 1 to 1½ yards in diameter, and one block, 2½ feet, was of Lammermuir (Silurian) Grit.
1. Rotten nodular Magnesian Limestone.

direction of the striations from that previously noticed may possibly be due to the pressure of the inferred Scandinavian ice-sheet, which is supposed to have united with that coming from Scotland, and may for a space have deflected the line of its onward march from the north-west. The cliff is about 30 feet in height, and shows the section given in Fig. 77. Stones derived from the Magnesian Limestone first appear in the Till south of Tynemouth.

In a later part of the Glacial epoch, smaller glaciers existed in the long dales of Durham and Yorkshire, for there are distinct moraines, which mark the gradual decline of the glaciers, and through which, and through the Boulder-clay, the rivers have cut their modern channels.

At Seaham ironworks and elsewhere, sands and gravels appear in the middle of the Till or Boulder-clay, and frequently thin away in wedge-shaped ends (Fig. 78).

Proceeding further south we find that in the Liassic and Oolitic region of Yorkshire the valleys which open upon the sea are apt to be more or less filled with boulder-clays, sands, and gravels, and the same phenomena occur in many parts of the high sea-cliffs. Thus the Drifts have in places blocked the old pre-glacial valleys, and the streams have cut independent channels. No Drift is found on the higher summits above 850 feet; but, as Mr. G. Barrow has pointed out, the ice must have ground over

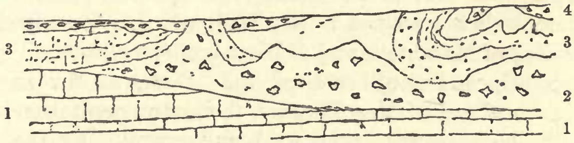


FIG. 78.—SECTION AT SEAHAM, DURHAM.

4. Boulder-clay.
3. Sand and gravel.
2. Boulder-clay.
1. Magnesian Limestone.

the rocks with no slight force, for at Eston Hill, a strip of Cleveland ironstone, some 150 yards long, 50 broad, and 11 feet thick, has been bodily lifted up the face of the hill to a point about 150 feet above its natural outcrop.

Much of the Boulder-clay in East Yorkshire has a purplish tint, due probably to the incorporation of red Triassic marls with Jurassic clays; it contains a great variety of boulders of Carboniferous Limestone, Lammermuir (Silurian) grit, basalt, greenstone, and other rocks. Many of these are subangular, and many are well rounded, and both kinds are often marked with glacial scratchings. Sections of the Drift may be seen in Cayton Bay, south of Scarborough, in Speeton Bay, and elsewhere. The Carnelians picked up on the sea-beaches along the eastern coast are derived from the Glacial Drift, which has transported them, with other materials, from various sources among the Palæozoic and Schistose rocks.

In the district of Holderness the Drift-deposits occupy what has been an old bay bounded by Chalk hills, and they are banked up against the old cliffs to a depth sometimes of 100 feet. The Basement Boulder-clay there contains transported masses of shelly sand and clay, known as the 'Bridlington Crag:' the shells are of an arctic character, and newer than any of the Pliocene Crag-deposits. Newer beds of Boulder-clay also occur at Hessle and other places, and intercalated with them are inter-glacial beds of gravel and clay, that have yielded a marine fauna, which was by no means arctic, and indicates a climate but little if at all colder than that of the same region at the present day. These beds are seen at Kelsey Hill, and they have yielded remains of Mammoth and *Rhinoceros leptorhinus*.

South and south-east of the Wash, as far as the neighbourhood of the Thames, there are great sheets of chalky boulder-clay, loam, sand, and gravel. By the late S. V. Wood, jun., and Mr. F. W. Harmer, they have been divided into Lower and Upper Boulder-clays, between which there are beds of sand and gravel, often contorted. These contain sea-shells and have been named 'Middle Glacial.' The shells have for the most part been derived from various Crag-deposits. The Lower Boulder-clay or Cromer Till is well seen at Bacton and Mundesley; it contains many striated boulders, some of Scandinavian origin. It is overlaid by the 'Contorted Drift,' a strangely disturbed series of loams and sands, containing huge masses or strips of Chalk that have been removed from the parent mass. The origin of these masses may be studied at Trimingham, where, as Mr. C. Reid has pointed out, the Chalk *in situ* has been bent up into a complete loop, the apex of which has been squeezed into the Glacial deposits. This movement, due to the action of the ice which formed the main Boulder-clay, would if carried further have entirely detached a mass of Chalk, such as elsewhere has been the case.

The Upper Boulder-clay (of the district) has been called the great Chalky Boulder-clay, from the circumstance that it consists of clay with a large amount of flint and chalk. Much of the material was ground up by a glacier travelling from north-east to south-west, the chalky and flinty débris being sparingly mingled with fragments of Lias, Oolite, Carboniferous Limestone, quartz, basalt, granite, &c., sometimes smoothed and striated. Though chiefly formed of chalky material, it also contains the rocks and fossils of the Kimeridge Clay, Oxford Clay, and Lias. Among the rocks, fragments of septaria are noteworthy, and among the fossils such forms as *Belemnites abbreviatus*, *Gryphæa dilatata*, and *G. arcuata* are abundant. The Boulder-clay seen on each formation that lay under the glacier ice-sheet, which was invading the country from north to south, partakes to some extent of the materials of the underlying rock; and this is found to be the case in passing westwards from Lincolnshire through Rutland into Leicestershire. Southwards the Boulder-clay extends to Bricket Wood, near Watford, to Finchley, and to the brow of the Thames Valley north of Romford (see Fig. 94, p. 286). Recently Mr. T. V. Holmes has observed small masses further south, beneath the Valley Gravel at Hornchurch.

It must now be evident to the reader, that on the east coast of England, and on the adjoining ground in the interior, through Northamptonshire, Leicestershire, and Warwickshire, there is no want of evidence of a cold episode or of episodes when snow and glacier-ice largely prevailed in these regions under some form or other; but the direct effects of glaciation have not been observed, except to the north of the Cotteswolds, of Edge Hill, Oxford, and the valley of the Thames above London. Indirect effects of the Glacial period may be found in the accumulations of rubble on the slopes of the Cotteswold Hills.

In older times the origin of the Boulder-clays was attributed chiefly to icebergs which, laden with moraine matter, broke from glaciers that descended to the sea ; and which, floating south and melting, scattered boulders and stony débris mixed with fine mud over the ocean-bed.

Of late there has been a tendency to attribute the origin of all, or almost all British Boulder-clays to the direct action of land-ice, and to look upon them as *ground-moraine* matter, the *moraine profonde* of Swiss and French authors. Thus they are supposed to have a modern parallel in the vast quantity of débris, believed to underlie and be pushed forward by the mighty ice-sheet that passes seaward from the great basin of central Greenland, and finds its vents through unnumbered fiords into Baffin's Bay. On these grounds both the Boulder-clays of the east of England are regarded as having been formed by the direct action of glaciers, the upper or chalky Boulder-clay being the work of the larger and later ice-sheet, when it happened that the cold had become most intense.

Assuming this theory to be true, the old glacier must have reached the plateau that overlooks the valley of the Thames. One difficulty in its acceptance occurs in the fact, that on the coast-cliff of Kessingland, near Lowestoft, there are beds of Boulder-clay which overlie soft false-bedded sands with gravel, and these sands lie apparently quite conformably and undisturbed beneath the Boulder-clay. If the latter was the *ground-moraine* that underlay a heavy glacier pressing southward, it is hard to understand why the sands there show no signs of pressure and glacial erosion. In a great many places, however, in East Anglia the strata beneath the chalky Boulder-clay are markedly contorted. This is the case where loams are interbedded with sands ; it is the case also occasionally with the Chalk and Norwich Crag. In other cases, as pointed out by Mr. Goodchild, the Drift may have resulted from the melting of the ice, and the consequent liberation of its stony and earthy contents.

It is not, however, necessary to suppose that glaciers are always needed for the production of ice-polished surfaces of rock and for the making of Boulder-clay, for, as shown by Professor H. Youle Hind, the formation of both on a large scale is now and has been for long in progress on the north-east coast of Labrador, through the agency of 'Pan-ice.' This is derived from bay-ice, floes, and coast-ice, varying from five to ten or twelve feet in thickness, all of which are broken up during spring storms. This broken ice is pressed on the coast by winds, and being pushed by the unfailing Arctic current, which brings down a constant supply of floe-ice, the pans rise over all the low-lying parts of the islands, grinding and polishing exposed shores, and removing with irresistible force every obstacle which opposes them; and the rock-masses pushed or torn from those surfaces are urged into the sea and rounded into boulder-forms by the rasping and polishing pans. Here, too, goes on the process of manufacturing Boulder-clay, for the deep hollows and ravines, at present under the sea, the records of former glacial work, are being filled with clay, sand, unworn and worn rock-fragments, producing a counterpart of some varieties of Boulder-clay.[1] As the British Islands during the Glacial epoch were more than once much in the same state as the north of Labrador, there can be little doubt that some of the British glacial phenomena were produced by the same causes.

On the Sussex coast near Pagham and Selsey there is an erratic deposit containing travelled boulders of granite, and many other rocks; and this deposit, according to Mr. C. Reid, affords clear evidence of the agency of floating ice. Grounding on the ancient foreshore this drift-ice dropped its burden of erratics between tide-marks, striating and pressing some of them deeply into the floor of Bracklesham Clay.

[1] See H. Y. Hind, 'Notes on some Geological Features of the North-Eastern Coast of Labrador,' *Canadian Naturalist*, vol. viii.; and J. Milne, *Geol. Mag.*, 1876, pp. 303, &c.

CHAPTER XXII.

PLEISTOCENE GLACIAL EPOCH.—MARINE DEPOSITS.

After the largest extension of glacier-ice, the land underwent a process of submersion, and while the great glacier was retiring, the diminishing ice, still descending to the sea, deposited moraine rubbish there. In Scotland, marine shells *in situ* are found at heights somewhat more than 500 feet above the level of the sea, and if the whole of Britain were then submerged only to that depth, it must have presented the spectacle of a group of islands.

Such islands, as far as Wales and Cumberland were concerned, still maintained their minor glaciers, which descended to the sea, where their ends broke off as icebergs, which, floating hither and thither, deposited their stony freights as they melted.

In many parts of England shell-beds associated with glacial material are by no means uncommon, and it is difficult to believe that in the high elevations where they sometimes occur, they had always been thrust up from the sea by glaciers. In Cheshire, near Macclesfield, lying between a lower and an upper Boulder-clay, Professor Prestwich found marine shells in sand and gravel at a height of about 1,200 feet; and at Congleton sea-shells are found 600 feet above the sea.

Shell-bearing deposits at a low level are found near the Mersey at Blackpool, on the coast north of the Ribble, and in Caernarvonshire in the district of Lleyn. Similar deposits were found by Joshua Trimmer, about five miles

SE. of Caernarvon, near the summit of Moel Tryfaen, at a height of about 1,400 feet above the level of the sea. They have been exposed at a slate quarry in the Cambrian rocks. In 1876 the section, which I saw in company with Mr. Etheridge, was as follows:—

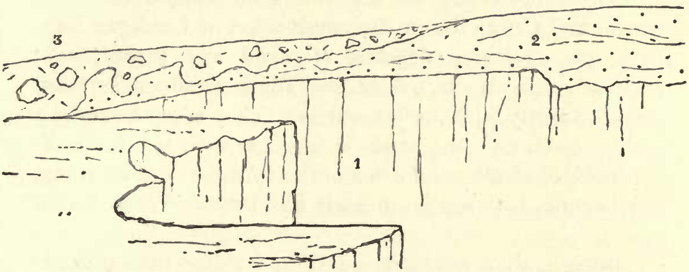


FIG. 79.—SECTION AT MOEL TRYFAEN.
1. Cambrian slate. 2. Shell-bearing sands and gravels. 3. Boulder-clay.

The sands and gravels are all marked by false-bedding, and have a beach-like aspect, with sea-shells, including *Astarte borealis*, *Tellina balthica*, *Cyprina islandica*, *Turritella terebra*, &c.

The surface of the sands beneath the boulder-beds is very irregular, and has been much eroded, probably by the pressure of a glacier during the deposition of the moraine-matter that forms the overlying Boulder-clay. The latter contains erratic blocks from Scotland, including Ailsa Craig, and from Cumberland, also large masses and smaller fragments of igneous rocks from the Lower Silurian mountains on the east, jasper, quartzite, purple and blue slate, Chalk-flints, &c., and looks like part of an old moraine. All the way up the slope, from the neighbourhood of Llandwrog, quantities of moraine mounds cumber the ground, and ice-scratched stones abound, and even small water-worn pebbles are marked by glacial striæ. Some of the blocks are very large. In the underlying gravels also stones sometimes occur, faintly marked by glacial striations, as if the materials, during the progress of submersion, had been derived from older moraines, and, being water-worn by attrition on the margin of the sea, the original sharpness of the scratches had been wellnigh obliterated.

At various levels on the low ground between Caernarvon and Criccieth, on the north coast of Cardigan Bay, there are extensive deposits of sand and gravel, well stratified, and much resembling those of Moel Tryfaen, but apparently without sea-shells. They are overlaid by boulder-beds, and the same is the case with similar half-consolidated strata on the sea-cliffs of Anglesey at Lleiniog, and beyond, between Beaumaris and Penmon near Puffin Island.

Putting all these facts together, I see no reason to get rid of the hypothesis published by me in 1859,[1] that, as a slow submersion of the land took place, the diminishing glaciers, still descending to the level of the sea, deposited their moraine-rubbish there, which matter was often remodelled by the waves to form sand and gravel. Gradually sinking more and more, and sufficient cold still continuing, the minor glaciers, descending from groups of icy islands, entered the sea and broke off in icebergs, which, as they melted, deposited their stony freights on the sands and gravels that more or less covered the bottom of the sea. To what depth this progressive submersion may have reached I cannot say; possibly it may not have been less than from 1,200 to 1,500 feet. This view is supported by Mr. T. Mellard Reade and others. If, however, we believe that these high-level shelly gravels were formed during a period of such great submergence, we have to account for the singular absence of contemporaneous and deeper-water beds formed at low levels. Moreover, it has been pointed out that the shells in these gravels indicate different depths of water and sedimentary conditions, so that they could

[1] *Peaks, Passes, and Glaciers*, 1859; and *Old Glaciers of Switzerland and North Wales*, 1860, p. 94.

not have existed together. A great number of the shells are broken and bear evidence of having been transported. Hence the view advanced by Thomas Belt, that the ice-sheet that passed through what is now the Irish Sea, carried away and pushed up portions of the shelly gravel and sand that occurred over its bed, and lodged them here and there on the heights. This view is accepted by Mr. C. Reid, Mr. P. F. Kendall, and others, because it is not inconsistent with the facts observed, and with what is elsewhere known of the transport of material, such as the Shap granite, to elevations much above its parent source.[1]

Reference has already been made to the marine shelly beds of inter-glacial age at Kelsey Hill; with these the shell-bearing gravels of March, in Cambridgeshire, have been compared. Some fluviatile and estuarine deposits and raised beaches, to which reference will be made, may belong to the same interval between the maximum glaciation and that of the latest development of ice-action in Britain. Mention, however, should be made of the Nar Valley Beds of West Norfolk, described by C. B. Rose. These are beds of brick-earth containing marine and estuarine Mollusca, and also bones of the Mammoth, &c.

In the low grounds that border the estuaries and alluvial plains of the Clyde, the Forth, the Endrick, and elsewhere, up to 125 and 262 feet above the sea, there are well-known brick-clays which sometimes contain erratic boulders and ice-scratched stones, perhaps derived from the Boulder-clay on which these brick-clays usually rest. At Chapel-hall, near Airdrie, to the east of Glasgow, these shell-bearing clays have been found at an elevation of over 500 feet. Here and there many sea-shells are found in these strata, all of existing species, but the general assemblage of forms indicates an arctic climate comparable to that of Greenland of the present day, a circumstance many years ago pointed out by James Smith of Jordanhill.

[1] A. R. Wallace, *Fortnightly Review*, Nov. 1893, p. 632.

The Mollusca include *Turritella terebra*, *Scalaria grœnlandica*, *Aporrhais pes-pelicani*, *Buccinum undatum*, *Natica clausa*, *Cyprina islandica*, *Mya truncata*, *Astarte borealis*, *Pecten islandicus*, *Saxicava rugosa*, and *Panopæa*

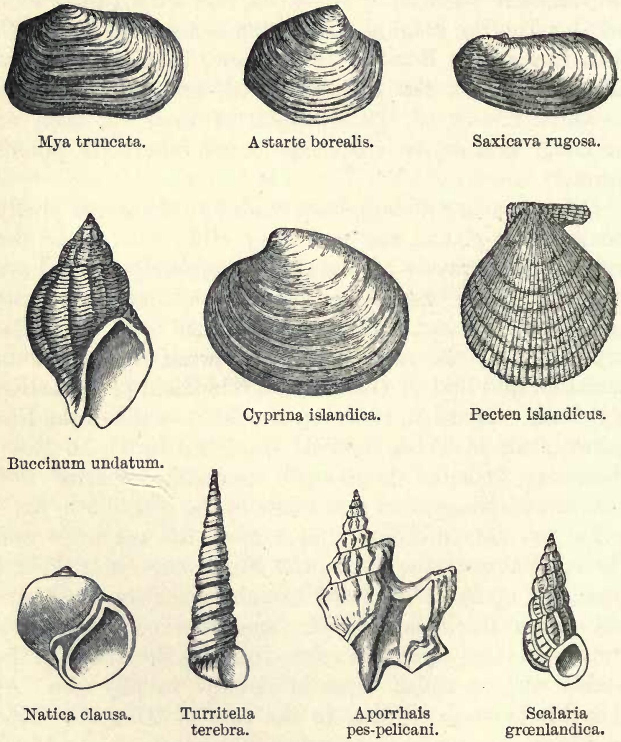


FIG. 80.—GROUP OF PLEISTOCENE FOSSILS FROM THE CLYDE BEDS.

norvegica. The evidence all tends to prove that these strata were deposited during a part of the Glacial epoch, probably towards its close (Fig. 80). They may be studied in brickyards at Paisley, and at other places on the low grounds bordering the Clyde, below Glasgow; they occur also along the Kyles of Bute and at Cumbrae. The high elevation of the Airdrie shell-bed was attributed by Carvill Lewis to the action of ice.[1]

After what seems to have been a long period of partial submergence the country gradually rose again, and the evidence of this I will prove chiefly from what I know of North Wales.

[1] See J. Smith, *Researches in Newer Pliocene and Post-Tertiary Geology*, 1862; A. Geikie, 'On the Phenomena of the Glacial Drift of Scotland,' *Trans. Geol. Soc. Glasgow*, vol. i. 1863; and H. C. Lewis, *Glacial Geology of Great Britain and Ireland*, 1894, p. 18.

CHAPTER XXIII.

PLEISTOCENE GLACIAL EPOCH.—NEWER BRITISH GLACIERS.

Referring now, for illustration, more particularly to North Wales,[1] we find that during and after the time of the great ice-sheet, the country to some extent sank below the water, and drift was deposited, and more or less filled many of the deep narrow valleys of Wales. It still remains in some parts of the broader expanses of the country. When the land was rising again, the glaciers gradually increased in size, although they never reached the magnitude which they attained at an earlier portion of the icy epoch. Still they became so large, that such a valley as the Pass of Llanberis was a second time occupied by ice, which, without invading Anglesey, spread itself into the lowlands beyond, and the result was, that the glacier ploughed out the drift and loose rubbish that more or less cumbered the valley. By degrees, however, as we approach nearer our own days, the climate slowly ameliorated, and the glaciers began to decline, till, becoming less and less, as they died away, they left here and there termina and lateral moraines, still in some cases as well defined as moraines in lands where glaciers now exist. Beautiful examples of such moraines are seen in the Pass of Llanberis, where there are heaps of boulders, clay, and angular gravel with blocks, identical in general aspect with many Swiss

[1] See also Ramsay, *The Old Glaciers of Switzerland and North Wales*, 1860.

moraines. Some of the loose stones are scratched, the lines crossing each other confusedly; and the mass of the moraine is formed of three or four mounds, which merge together at their bases, and mark on a small scale the gradual decrease of the Cwm-glas glacier. These circle

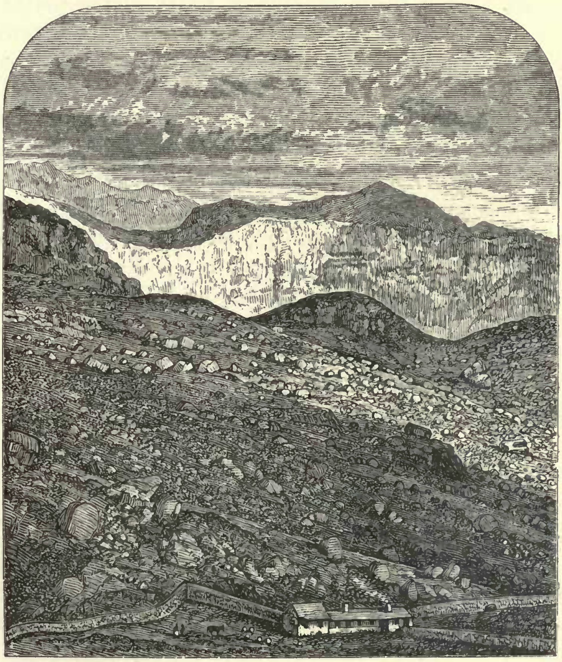


Fig. 81.—View in the Pass of Llanberis.

Moraines and *Roches moutonnées* between Cwm-glas and Blaen-y-nant.

round the lower side of a large *roche moutonnée*, which forms a small hill, as shown in front of the cliff in the middle of Fig. 81.

A little behind this hill, about half a mile south of Blaen-y-nant, a terminal moraine, grass-grown, but strewn with travelled blocks, ranges across the valley between two brooks, and is almost as regular in form as an artificial earthwork. It is between 1,200 and 1,300 feet above the sea. Higher up, on the west side of Cwm-glas, the striæ on the rocks run NNE. below the space where the glacier, in a cataract of ice, once slid down the cliff that now appears so grim. Four white threads of water glance on its side, the sole representatives, in another form, of the jagged ice-fall, that on a smaller scale must have resembled the ice-cataract of the glacier of the Rhone. Beyond this cliff, in one of the innermost recesses of Snowdon, lies an upland valley bounded on three sides by tall cliffs, in the midst of which lie two small, deep, clear tarns about 2,200 feet above the sea, each in a perfect basin of rock. Between these pools and the cliff below, a large quantity of moraine-débris, derived from Crib-goch, cumbers the ground. The rocks on which it lies are often smoothed, rounded, and deeply grooved; and the striæ that, lower down the valley, strike straight towards the Pass, here branch to the south-west and south-east, following the courses of two minor valleys on either side of a peaked ridge that descends from Crib-goch to the ground between the pools. Tiny moraine mounds scattered about tell of the last remnants of ice ere the shrunken glaciers finally melted away in the upper recesses of the mountain.

From the summit of Snowdon three of the old glacier valleys may be seen to radiate from the mountain. On the east, the magnificent amphitheatre of Cwm-glas and Llyn Llydaw, with its *roches moutonnées*, moraine mounds, and numerous perched blocks; on the south, the deep glen of Cwm-y-llan, with its ice-worn surfaces of rock on the sides of the hills, on which, just below the peak of Snowdon, there is a moraine about half a mile in length, formed in the latter days of the glacier, that once flowed down to join the larger ice-stream that descended through Nant Gwynant to below Beddgelert.

It would be easy for me to give a similar description of the large glacier that filled the valley of Nant Ffrancon, and flowed onward to where Bangor now stands, where, as a terminal moraine, it deposited those beautiful and now wooded mounds that form the park of Penrhyn Castle. Further up the valley, beyond Ogwen Bank, the river is barred by striated grits, dotted with erratic blocks, and high above is the craggy tributary valley of Cwm-graianog.

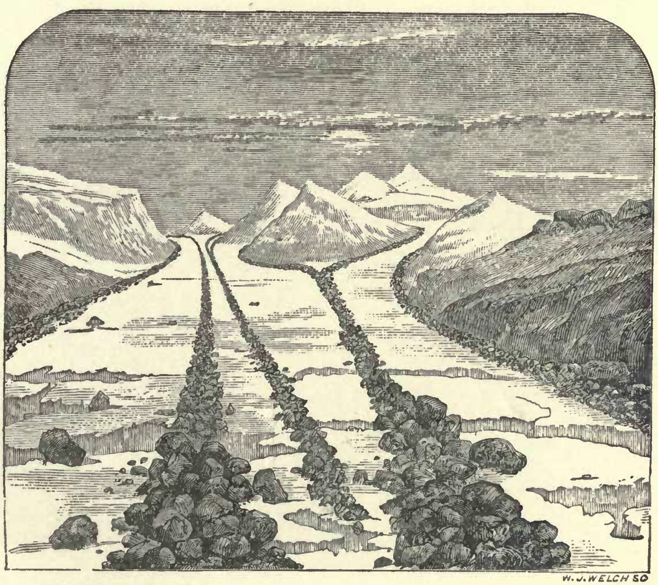


FIG. 82.—THE GLACIER OF THE PASS OF LLANBERIS.

Its whole length is not over half a mile, and at its mouth, above the steep descent to Nant Ffrancon, a small but beautifully symmetrical moraine crosses the valley in a crescent-shaped curve.

Another striking example of the moraines of a retreating glacier may be seen in Llyn Idwal, first described by Darwin in 1842. Below an amphitheatre of steep hills and cliffs lie the waters of Llyn Idwal, which are dammed up by ice-worn rocks strewn with moraine-material. Below the moraine, down to the Ogwen, the rocks are strikingly *moutonné*, the striations gradually curving round to take the direction of the main valley. On either side of Llyn Idwal lie several moraines, which run in long regular mounds lengthwise in the valley, and were deposited at intervals at the side of the glacier when it ceased to fill the

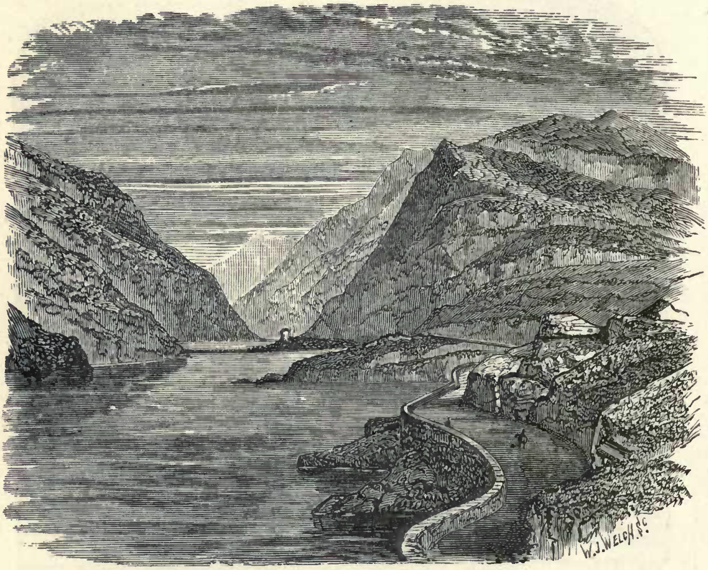


FIG. 83.—LLYN PADARN, PASS OF LLANBERIS.

valley from side to side, and was gradually decreasing in size. When the ice of these later glaciers of Llanberis and Nant Ffrancon was thickest, it could not have been less than 1,300 feet thick in the former, and from 1,000 to 1,200 feet in the latter. In the valley of Llanberis there are two well-known lakes, Llyn Padarn and Llyn Peris, and on a clear day, when the water is still and pure, from a boat one can see boulders here and there lying on the bottom of the shallower parts of the lakes. In Fig. 82 the Pass of Llanberis is represented as it may have been at some period when from end to end it was comparatively full of ice. In Fig. 84 it is shown as it must have existed for a time when the glacier, by amelioration of climate, had retired from all the lower parts of the valley, and

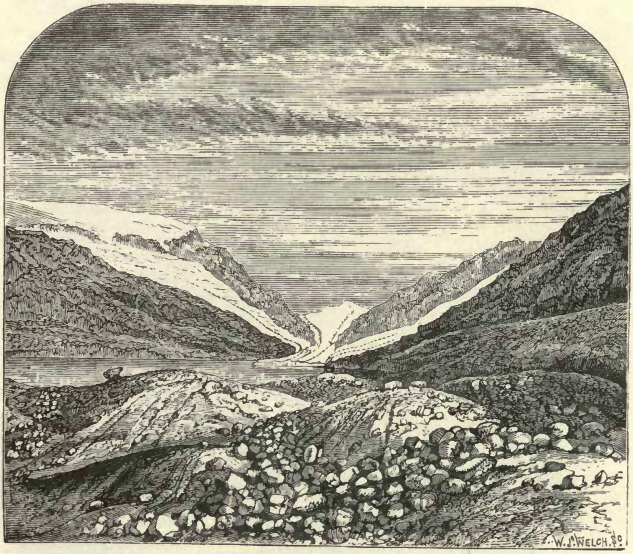


Fig. 84.—An Episode in the History of the Glacier of Llanberis.

debouched into an upper part of what is now Llyn Peris. As it gradually receded, moraine stones, that fell from its end, got scattered over the bottom of the lake; for in those days there was no alluvial flat and no short river to divide into two the old lake, then more than five miles in length. In the foreground are the block-strewn *roches moutonnées* on which Dolbadarn castle now stands, and which here and there are still marked by distinct glacial striations.

The gradual retreat of the glacier of the Pass of Llanberis is further proved by numerous *perched blocks*, which, here and there, isolated or in groups, stand on the surfaces of *roches moutonnées*, as, for example, at Pont-y-gromlech, and in many other places. There masses of stone

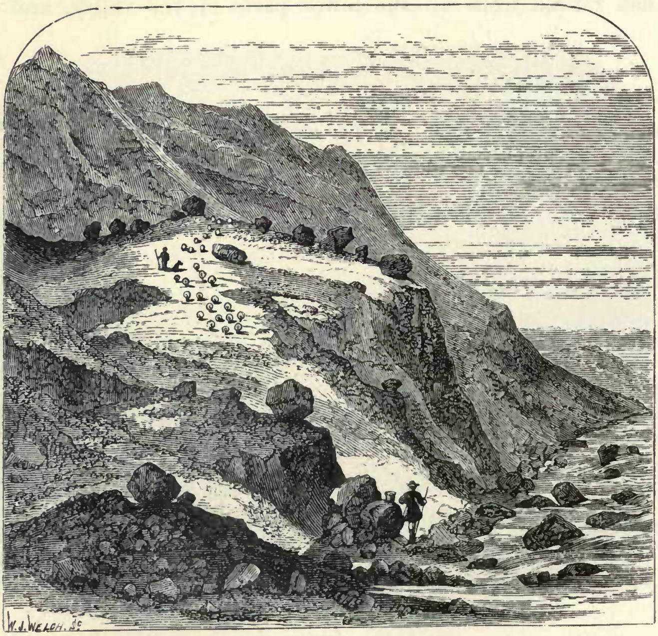


FIG. 85.—VIEW IN THE PASS OF LLANBERIS.

Roche moutonnée, with *Blocs perchés*, Pont-y-gromlech.

that, so to speak, floated on the surface of the ice, were left perched upon the rounded rocks in a manner somewhat puzzling to those who are not geologists; for they lie in situations to which they cannot have rolled from the mountains above, because their resting-places are separated from it by a hollow; and, besides, many of them stand in positions so precarious, that had they rolled from the mountains, they must, on reaching the points where they lie, have taken a final bound and fallen into the valley below. Hence we conclude that, as the glaciers declined in size, the errant stones 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

FIG. 86.—OLD GLACIER CIRQUES IN ARRAN, FROM LAGAN HILLS.

level. Finally, the climate still ameliorating, the glaciers shrank farther and farther into the heart of the mountains, until, at length, here and there, in their uppermost recesses, we find the remains of tiny moraines, marking the last relics of the ice before it disappeared from the country.

The same kind of evidence of a period of greatest glaciation, followed by partial submersion, re-elevation, and the gradual retreat of the later glaciers, is plain in almost every valley in Cumberland, as shown by Clifton Ward.

In Scotland also the land underwent partial submersion and re-elevation during the Glacial epoch, and the gradual retreat of the later glaciers is witnessed in many a valley in the Carrick and Lammermuir Hills, in the moraines of the cirques of Arran, and through the mainland of the Highlands, in the Orkney Isles, and also in Skye, in Glen Sligachan, and other valleys among the Cuillin Hills. The most striking features that still bear witness to the retreating glaciers are the 'Parallel Roads' of Glen Roy. To the east of the Great Caledonian Glen, in the district of Lochaber that lies east of Loch Lochy, we find the famous long and deep glen 'with its three bars, straight and distinct as if they had been drawn with a ruler, yet winding into all the recesses of the steep slopes, and coming out again over the projecting parts without ever deviating from their parallelism.'[1] The origin of these 'Roads' has proved a fertile source of discussion: marine, fluviatile, and glacial agents having alike their champions. The 'Roads' consist of three horizontal shelves or terraces, 210 and 85 feet apart, and made up of coarse angular and water-worn detritus. The explanation generally accepted is that of Mr. T. F. Jamieson, who has maintained that during the decline of the glaciers, glacial lakes were formed in some of the lateral valleys, the streams being dammed back by the ice which still occupied the main valleys. Along the margin of the lake the detritus accumulated, and in some places pebbles are found where the lake was most exposed to agitation by the wind. The water was, however, lowered successively from 1,150 to 1,065 and 855 feet above sea-level, a decrease attributed to the melting of the icy barrier.[2]

Again, when the glaciers were retiring westward, up

[1] A. Geikie, *The Scenery of Scotland*, ed. 2, 1887, p. 266.

[2] Jamieson, *Quart. Journ. Geol. Soc.*, vol. xix. p. 235; vol. xlviii. p. 5; see also J. Geikie, *The Great Ice Age*, ed. 2, 1877, p. 227.

the dales of Yorkshire and Northumberland, the ice left, as it retreated, heaps of débris originally forming irregular mounds, often enclosing cup-shaped hollows; but these, which sometimes remain in the more recent and smaller moraines, have in the more ancient and larger ones often got filled up by help of rain washing the fine detritus into them; and the whole has become so smooth that the original *moundiness* has, by degrees, been nearly obliterated. In like manner the same has taken place in the wide valley that crosses England eastward from the bend of the river Lune, near Lancaster, by Settle to Skipton, including most of the country between Clitheroe in Lancashire and Skipton, and as far south as Pendle Hill and the other hills that border the Lancashire Coal-field on the north.

There is often great difficulty in distinguishing between these later moraines and the great masses of moraine-matter which were formed during that earlier period when the northern ice-sheet covered the greater part of Britain, and which undoubtedly were not terminal, but actually lay under the ice as *moraines profondes*.

Again, in certain stages of the history of the period, the larger sheet or sheets of glacier-ice covered the hills and filled the valleys so thickly and completely that, pushing out to sea, they even excluded it from parts of valleys that were at a lower level than the sea itself; and moraine-matter thus got sorted and mingled with other marine deposits. This partly accounts for the gradual merging of those gravelly mounds, called Kames or Eskers,[1] into Boulder-clay and true moraine heaps full of ice-scratched stones. The Eskers themselves are often largely charged with water-worn stones originally well ice-scratched, and their peculiar structure is shown in the diagram (Fig. 87). These glacial scratchings have since been almost entirely worn away by friction, the stones having been rubbed

[1] The term Kame is used in Scotland, and that of Esker in Ireland; but the latter term is more generally adopted.

against each other by moving water; so that but faint traces of the original scratchings now remain.

The Eskers form marked features, more especially in the low grounds of many a glaciated district, standing out like great embankments in some areas, with numerous smaller ridges and mounds. Their origin has probably been varied, in some cases torrential; in others they may have been formed as 'bars' near the mouth of a river, aided by tidal currents.[1] Local glaciers may have exerted some influence, for, as Mr. Jamieson has remarked, a temporary advance of a glacier over a gravelly plain might raise it into steep curving mounds along its border. Much of the low ground around Belford and Lucker, in Northumberland, is formed of these singular mounds,

FIG. 87.—SECTION OF AN ESKER. (J. G.)

beautiful examples of which are to be seen in Lanarkshire and Wigtonshire, and again on the eastern borders of Sutherlandshire, and in many other areas in Scotland. Many of these held tarns in the hollows of the mounds, but they are now mostly filled with peat.

The foregoing sketch of the Glacial epoch is of much importance from a geological point of view, more especially because of the pictures we get of phases of a physical geography in these regions so different from that of to-day, and which judged by any geological standard is yet so recent. Besides, the events of this period of plentiful snow and ice gave distinctive characters both to our

[1] See Green, *Physical Geology*, 1882, p. 632; and J. Geikie, *Great Ice Age*, ed. 2, p. 210.

mountains and much of our lowlands, different, in many respects, from those of mountain ranges and lowlands where glaciers never were. No one with an eye educated in glacier work can fail to recognise the moulding by ice of the features of the Highland and Cumbrian mountains. Their outlines are often smooth and flowing curves, and, excepting here and there, cragginess is not their special characteristic. In North Wales the mountains are apt to be more craggy, partly because of the varying hardness of the rocks, and partly because, being further south, that region was, in later Glacial times, not so completely smothered in ice as the more northern mountains.

CHAPTER XXIV.

PLEISTOCENE GLACIAL EPOCH.—ORIGIN OF CERTAIN LAKES.

There is an important subject connected with the physical geography of our country, and that is, the multiplicity of lakes in the mountain regions; and the question arises, by what physical operations do they happen to be so numerous in some districts and so scarce or altogether absent in others?

When glaciers descended into valleys, and deposited their terminal moraines, it sometimes happened that when a glacier declined in size its moraine still remained tolerably perfect, with this result—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 several among the mountains of Wales, which at least are partly dammed in by moraines, and a few, perhaps, entirely so. They are always small, and may be classed as tarns, lying at the bases of cliffs in the upper recesses of the mountains. Some small lakes, however, are only partly blocked in by moraine-matter, and, like some of the large lakes on both sides of the Alps which have moraines at their outlets, even if these moraines were removed they would be found to be entirely enclosed by solid rock formations. Such lakes in Wales 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 other countries.

There is indeed no point in physical geography more difficult to account for than the origin of many 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 can be easily proved to be *rock-basins*—that is to say, hollows entirely surrounded by solid rocks, the waters not being retained by mere loose detritus. But the great difficulty is, how and why were such large numbers of these *rock-basins* made in special regions?

A great many lakes lie in valleys; but what is the effect in any country of running water? Rivers cannot make large basin-shaped hollows surrounded by rocks on all sides. All that running water can do upon the surface is to scoop out trenches or channels of greater or less width, forming gorges or wider valleys, according to the nature of the rivers and the rocks. Neither can the sea make a deep hollow below its own average level in hard rocks.

It has been contended that many hollows 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 those of Geneva, Thun, Lucerne, Zurich, Constance, and the great lakes on the Italian side of the Alps, or many of the Welsh, Cumberland, and Highland lakes, and examine the rocks critically, we find that they do not lie in the form of basin-shaped, synclinal hollows, but, on the contrary, the *strike* of the strata often runs right across the lake-basins instead of circling round them. Again, the rocks may be bent and contorted in a hundred curves all along the sides and under the length of the lake. Such synclinal depressions are the rarest things in nature: that is to say, hollows formed of strata bent upwards at the edges all round into the form of a great dish, the very uppermost bed or beds of which shall be continuous and unbroken underneath the water of the lake. Some such synclinal hollows are found in the upper valleys of the Jura, but without lakes, and in which the drainage runs into *potholes*, and finds its way to the level of the Val de Travers, where rivers issue from caverns in the Secondary rocks. The Swiss and other valleys generally, and the lake-valleys in particular, do not lie in gaping rents, fissures, or in synclinal curves; and there is no necessary connection between fractures and the formation of valleys, excepting that in certain cases a line of fracture was also a line of weakness, on which the watery agents that promote denudation were more easily able to work, especially if on each side of a fault the rocks were of different degrees of hardness.

It might, however, be said that these lakes lie in areas of special depression, made by the sinking of the land underneath each lake. So difficult indeed did it seem to Playfair, the great illustrator of Hutton, to account for the origin of the rock-basin in which the Lake of Geneva lies, that he was forced to propound the hypothesis that beds of salt had been dissolved underneath its bottom, which therefore sank, and so formed a hollow for the reception of its waters! Meres may be occasionally formed in this way, or by the dissolution of calcareous rocks. Some small sheets of water owe their existence to inequalities in the Drift, especially in the region of Eskers. Others, like the Broads of Norfolk, may lie in hollows of old estuaries from which the sea is barred out. Again, some lakes may occupy extinct volcanic craters; in volcanic regions they may be due to special subsidence, and in other districts even to earth-movements on a far grander scale. The origin of the great lakes of Africa is not here considered, any more than the origin of the Black Sea, the Caspian, or the Sea of Aral.

Lakes are, however, so numerous in the Alps, North Wales, Cumberland, and the Highlands of Scotland, where they occur by the hundred, and in part of North America by the thousand, that the theory of a particular depression for each lake will not hold in these or in any other region that has been acted on by glacier-ice on a great scale. In that part of North America which lies well east of the Rocky Mountains, and north of latitude 40°, it is as if the whole country were sown broadcast with lakes, large and small; and great part of the country not being mountainous, but consisting of undulating flats, it becomes an absurdity to suppose that, so close together, a special area of depression was provided for each lake. The physical geology of America, Scotland, and Sweden, for example, entirely goes against such a supposition; and it is equally untenable for the Alps and the lowlands between the Alps and the Jura.

If, then, we have disposed of these erroneous hypotheses, what is left? If the sea cannot form such hollows, nor weather, nor running water, and if the hollows were not formed by synclinal curves of the strata; if, in short, the lakes do not lie in gaping fissures, nor in areas of special depression, the only known remaining agent is the denuding power of ice.

In the region of the Alps it is a remarkable circumstance that all the large lakes lie in the direct channels of the great old glaciers—each lake 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. This is not the case, but rather the reverse.

The Lake of Geneva, once more than fifty, is now about forty miles long, its upper end having been filled with moraine-matter and alluvium, which form a delta. In its broadest part about twelve miles wide, the lake lies at the mouth of the upper valley of the Rhone and directly in the course of the old glacier. This was more than a hundred miles in length from the present glacier of the Rhone to where at its end it abutted upon the Jura, by about 130 miles in width at Geneva, from south-west to north-east, at what was once considered to be its lower end. There, however, it is now known that its bulk was swelled by tributary glaciers descending from Mont Blanc, and from the high Alps further south, so that its most westerly edge lay at least sixty miles beyond Geneva, as far as Lyons on the Rhone.

It seems probable that, during the most intense part of the Glacial epoch, the whole of Switzerland between the Alps and the Jura must have been covered with glacier-ice. If so, it must have been impossible to specialise individual glaciers such as those of the Rhone, the Rhine, the Linth, the Reuss, and the Aar. No doubt in some form those valleys existed, in which case the great glacier, maintaining an average uniformity of surface, must still have been thickest in the lines of the pre-existing valleys, and the erosive power of the moving ice must have been proportionally increased thereby. The effects produced on the country over which the undercurrents of the Rhone and other glaciers flowed were commensurate to their great size and thickness.

The Lake of Geneva where deepest, towards its eastern end, is a little more than a thousand 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 descended, we are able to ascertain what was the thickness of the ice in that valley when the glacier attained its greatest size; it may have been nearly 4,700 feet thick. By similar observations on the Jura, it is clear that where the ice abutted on that range, it still maintained a thickness of something like 2,200 feet where thickest.

Consider the effect of this gigantic glacier flowing over the Miocene rocks, which in this part of Switzerland are comparatively soft, and yet of unequal hardness! That mass, working slowly and steadily for a period 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, especially on the softer Miocene strata, and the underlying rock was consequently to a corresponding extent worn away. No one can doubt that the ice-flow that pressed down the upper valley of the Rhone exercised a great amount of eroding power, representing as it did the snow-drainage of all the southern slopes of the Oberland, and the northern drainage of all the southern Alps, from Mont Blanc to the Mutthorn, which looks down on the modern puny glacier of the Rhone. At its western end, near Geneva, the ice was wider and thinner, and there the pressure and grinding power were less, and the waste of the underlying rock was proportionately diminished. The result was, that a great hollow was scooped out, about 1,000 feet in the deepest part, without allowing for the moraine-matter that, in later times, must have been left in the depths of the lake by the retreating glacier, or for more modern sediment that covers the bottom. At first it may be difficult to realise this theory and to appreciate the mode of action of the ice, but when we compare the depth with the length of the lake and the height and weight of the ice above, and reduce all to a true scale, as shown in Fig. 88, it becomes evident that the depth of the rock-basin is comparatively quite insignificant.[1]

While taking the Lake of Geneva as a special example, the lakes of Llanberis, Llyn Llydaw, and Bala in Wales, Windermere in the Cumbrian region, Loch Doon in Ayrshire, Loch Katrine, or Loch Lomond, and many other lakes in the Highlands, would on a smaller scale do as well. All the lakes in Cumberland appear to lie in true rock-basins (unless, in some cases, a few of the smaller ones may be dammed up by mere moraines or other superficial detritus); and this has been confirmed by Clifton

[1] See Ramsay, 'On the Glacial Origin of certain Lakes,' *Quart. Journ. Geol. Soc.*, 1862, vol. xviii. p. 185; also article by A. R. Wallace, *Fortnightly Review*, Dec. 1893, p. 750.

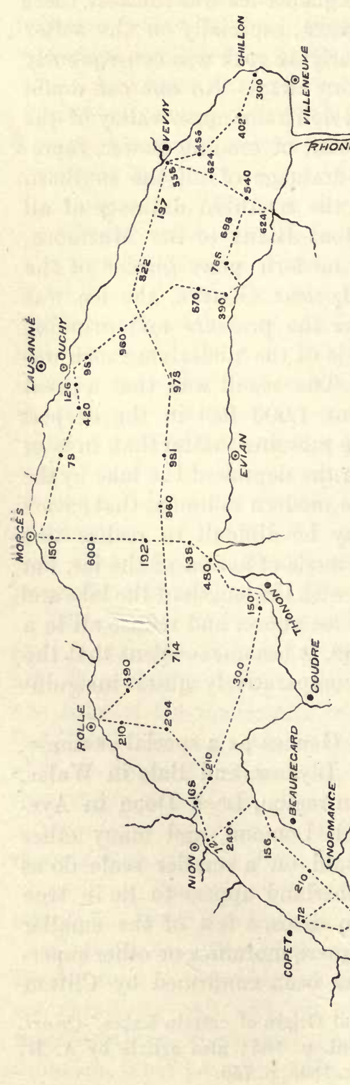


FIG. 88. LAKE OF GENEVA AND SOUNDINGS.

FIG. 88A.—OLD GLACIER OF THE RHONE, COVERING WHAT IS NOW THE LAKE OF GENEVA.

The shaded part represents the rock-basin beneath the lake. The dark line the lake, showing its depths on a true scale. The light part above represents the Old Glacier of the Rhone. The figures indicate the depth of the lake in feet.

Ward. The glacial origin of many of the lakes in Ireland is equally clear.

In Scotland, in the southern hills, and in Kirkcudbrightshire and Ayrshire, there are many truly rock-bound lake-basins scooped out of the Silurian rocks of the Carrick Hills. If anyone wants a convincing proof, let him go to Loch Doon, where at the outflow of the lake he may see the rocks perfectly *moutonnée* and well grooved, sloping under the water in a manner that unmistakably marks an ice-worn rocky barrier, while elsewhere the lake is encircled by mountains, the highest of which is more than 2,800 feet in height. In the Shetlands and the Orkneys, in Lewis and all the Western Islands, in Sutherland, Ross-shire, Inverness-shire, Perthshire, Dumbartonshire, and the Mull of Cantyre, the country is, as it were, sown with lakes—a number of which lie in true rock-basins.

Let anyone climb to the summit of Suilven in Sutherland, which rises sharp and steep-sided above a broad, bare, undulating plateau of gneiss (p. 316), and let him count the lakes, large and small, seen from the top. On one side alone forty-two could be counted; and turning round to the other sides, their name is legion! Most, if not all, of these lie in rock-basins. In the Shetland Isles some of the lochs, as noticed by Messrs. Peach and Horne, occur in ice-made rock-basins, while others are due to irregular deposition of Glacial Drift.

Rock-bound basins are, however, not confined to the land, for they are almost universal in the bottoms of fiords, or, as they are called in Scotland, Salt-water or Sea Lochs, which so largely intersect all coasts where glaciers are or have been. These long, narrow, mountainous arms of the sea are but continuations of inland valleys, which, it is well known, were, in Scotland as in Norway, filled with glaciers.

Though no doubt many seaward extensions of land-valleys, now fiords, were once dry valleys themselves, and the deeper hollows in them were sometimes excavated

FIG. 89.—LOCH ERIBOL, SUTHERLAND.

when the whole stood above the level of the sea, yet this is not essential; for, as observed by Amund Helland, if a great glacier be sufficiently powerful to push onward, and grind for many miles along the bottom of a long fiord, the scooping out of rock-bound basins will be much the same as if its whole length were above the level of the sea.

It may be that in Wales the estuary of the Mawddach was an old lake or rock-bound fiord-basin now greatly silted up, for the frequent *roches moutonnées* opposite Barmouth, once islands, seem to indicate a rocky barrier there.

When, however, we go into Scotland, where the mountains are high and the valley ice-streams were thick, there is no lack of such fiords. From Loch Eribol, with its ice-ground mountains and islets, Fig. 89, to the Firth of Clyde, there is not a fiord that is not deeper in its further recesses than at its mouth, a fact proved by the charts of the Admiralty. The small fiord of Loch Eribol is 78 feet deep near its upper end, and much shallower at its mouth. Halfway up, Little Loch Broom has a depth of 342 feet, and at its mouth is nowhere deeper than from 60 to 156 feet. Loch Fyne, about eight miles below Inverary, is 414 feet deep, and is very much shallower 15 miles further down, while in Loch Etive, near Oban, the whole theory is brought prominently before the eye, as shown in the accompanying picture, Fig. 90.

The mouth of this sea-loch or fiord at Connal Ferry is so narrow, that it seems as if a stone might almost be thrown across, but further up it spreads into a noble sheet of water, and its length is about 20 miles, and its greatest depth 456 feet. When the tide is up, on a quiet day, all is still and unruffled from end to end; but as the tide falls the water gets troubled across the mouth of the fiord, two rocky islets begin to appear, and by-and-by, standing on the *roche moutonnée* in the foreground, it becomes plain that a rocky barrier traverses the fiord from side to side, over which the outflowing water falls with a roar that

Fig. 90.—Mouth of Loch Etive, Connal Ferry.

may be heard for a mile or more. If the region were raised for a few feet, Loch Etive, by influx of rivers, would by degrees become changed into a fresh-water lake, like its neighbouring tributary rock-bound basin Loch Awe, which attains a depth of 306 feet. Coruisk in Skye is another case in point on a smaller scale. Here then is what may be called a demonstration of the glacial origin of many rock-bound fiord-basins, unless we can persuade ourselves to believe that all the great fiords of Scotland, Norway, and other regions, were by some special operation upheaved at their mouths, no matter how the inlets trend, so that some day when these countries may be further elevated, the fiords shall all be converted into inland rock-bound fresh-water lakes!

Finally, if I were to classify lakes directly and indirectly produced by glacial action, it would be as follows—the first named being most and the last least numerous: 1st. True rock-basins scooped by glacier-ice out of the solid rocks. 2nd. Lake hollows due to irregular accumulation of moraine-matter on broad flattish surfaces, among which in many districts may be included those dammed in by Eskers or Kames, good examples of which, on a small scale, may be seen at Carstairs, and in the beautiful grounds of Castle Kennedy near Stranraer. Many of these lakes since their formation have got filled with alluvial detritus, and are now peat-mosses. Meres which have been barred by Drift occur in some parts of Cheshire, in Delamere Forest, and at Ellesmere. There are also many small hollows formed in original irregular accumulations of the boulder-clays of Northumberland and Durham, now filled with laminated clays, sands, and bearing fresh-water shells and plant-remains, and some of these shallow lakes still exist as such. 3rd. Moraine-dammed lakes, which I think on the whole are scarce, for many that appear to be so, are in reality more than half rock-basins, or only dammed up by moraine-matter for a part of their depth.

CHAPTER XXV.

PLEISTOCENE AND RECENT EPOCHS.—BONE-CAVES.

THE Boulder-clays to which attention has been already directed, were formed during a period of cold, accompanied by the great glaciers that covered so much of the north of Europe. Subsequently the country slowly sank, and, severed from the mainland, became merely groups of islands. Again, however, it was elevated, and there is evidence that it was then united to the Continent, for we find in later deposits the remains of a number of terrestrial animals, some of the species of which are unknown in the older formations. The Elephants which lived before this time must have been driven out of our area by that submergence, unless some of them, with other Mammalia, managed to live on in the extreme south of what is now England, which apparently suffered a smaller change of level. On the re-elevation of the country, it must have been reunited to the Continent, because the Mammoth or great hairy elephant, *Elephas primigenius*, then appears, associated with a number of other animals which, after the re-elevation of the land, migrated from the Continent of Europe to our area, and whose bones are found in the old alluvia of rivers. If, as is stated, a variety of the Mammoth, *E. primigenius*, occurs in the Forest-bed, then it came into the British area before the beginning of the Glacial epoch; but as the Mammoth is found chiefly in what appear to be inter-glacial strata, it seems improbable that it obtained any particular footing in our area in pre-Glacial times.

In connection with this subject it is now necessary to say something of the bones found in limestone-caves, especially as the subject is intimately connected, not only with a large and partially extinct mammalian fauna, but also with the presence of man as a hunting denizen of the British area, at the time when the larger and now extinct Mammalia roamed the country.

Bone-caves are often of very old date, and always occur in limestone strata, in which they have been formed in consequence of part of the carbonate of lime having been dissolved. Most solid limestone rocks are jointed: that is to say, they are parted by narrow fissures, often vertical,

Fig. 91.—Section of Cave in Limestone. (J. G.)

a, Entrance. *b*, Cave-earth, &c. *c*, Stalactites. *d*, Stalagmites. *f*, Blocks fallen from roof of cave. *p*, ' Pipes ' or fissures filled with débris.

through which water that falls on the surface can easily find its way. Rain-water percolates through the joints, and the carbonic acid, picked up by the water as it falls through the air, by degrees dissolves part of the limestone, and carries it away in solution in the form of bicarbonate of lime. Running in underground channels, fissures have been widened and caves have thus been formed, often of great extent, and branching in many directions, through which streams still sometimes run. On the sea-coast such fissures are often enlarged by marine action.

Close to Clapham, in Yorkshire, in the grounds of Ingleborough, a large cave runs from the side of a limestone gorge into the hill, 800 yards in length, and no doubt further if it were followed. From its top, 'like natural sculpture in cathedral cavern,' beautiful stalactitic pendants and pillars descend to the floor; delicate open arcades run along the ledges, large fretted accretions of stalagmite swell out in the angles of the cavern between the floor and sides, and great flat pendants of stalactite hang like petrified banners from the walls. Sometimes the cavern runs in a long low gallery, sometimes it rises into high chambers, scooped into ogee arches; and wherever a chamber occurs, there we find a joint in the rocks, through which water from above percolates, and continues the work of sculpture. The whole is the result of the dissolving of carbonate of lime by carbonic acid in the water; and modern drippings and a rivulet in the cavern still carry on the work through all its length. In the Cheddar Cliffs, in Somerset, there are also fine caverns with beautiful stalactites; and near Wells there is Wookey Hole, noted for its size. In these particular caverns no bones of special account have been found; but others in the same district and elsewhere have yielded remains of the highest interest.

It is impossible to fix with absolute accuracy the precise age of such caves, or the time when all the bones that are found in them were buried there; for the wearing out of the caves has been going on for vast periods of time, and some of them may have been filled with sediments, perhaps charged with bones, again and again. There is often proof that, by underground changes of waterflow, old consolidated gravels that filled the caverns to the roof have been, at various periods, forcibly cleared out by natural means. When, therefore, we find bones in these caverns, mixed with red loam, sand, gravels, and angular fragments of rock, it is very difficult, and perhaps sometimes impossible, to define to what precise *minor period* they belong.

Sometimes the animals found their way in through the mouths of the caverns; at other times their remains were washed in through 'potholes' and openings in their roofs.

On the verge of the mouths of large bell-shaped potholes, on the Carboniferous Limestone plateaux of Yorkshire, under which we hear the water rushing, there may often be seen the carcases or detached bones of sheep, and these, during heavy rains, will be carried below. Often the bones of animals, or the animals themselves, have been dragged by beasts of prey, such as Bears and Hyænas, into these caves. One evidence of this is, that the bones have been gnawed, for they still bear the marks of the teeth of carnivora, as first shown by Buckland; and another, that the angles of the caverns themselves are occasionally smooth, having been polished by the animals rubbing against the rock, as they passed into and out of their dens.

Possibly many of these caves date from before the Glacial epoch, and bones of animals may have found their way into some of them before as well as during that period. There is no doubt, however, that since the glaciers died away many of the caves have been more or less tenanted down to the present day, or bones have been at intervals washed into them. They thus contain organic remains of various dates; many of the animals still inhabiting our country, others being extinct here, though some are still living on the Continent.

Mingled with the bones of extinct and modern species in England and Wales, flint implements, and other works of man, have been found; and these, like the bones of animals, belong to different minor epochs. During part of the time some of the caves in the south of England seem to have been inhabited, while others farther north lay underneath the ice-sheet, so that part of the northern land was desolate, and for a time uninhabited by beast or man. This, however, is certain, that man, the Mammoth, and other extinct mammalia, were contemporaneous.

The bones of wild animals, together with implements made by man, have in all the caverns generally been preserved in much the same manner. Often, in some of the lower strata of caverns, they lie in a red loamy earth

(*Cave-Earth*) mixed with stones. Over this there frequently lies a thick deposit of *stalagmite* or carbonate of lime, deposited from water dropping from the roofs of the caverns. In this way bones became sealed up in the caves safe from the effects of air and, to some extent, of moisture; and the result has been the natural burial and preservation of those old races of animals that formerly inhabited our land.

England and Wales are peculiarly fortunate in the possession of so many dens and caverns, most of which have been excavated by natural processes in the Carboniferous Limestone, which forms such large tracts of country. The remainder are chiefly in the Devonian Limestone of Devonshire, while a few are in the Magnesian Limestone, the Oolitic, or other limestone strata. In connection with this subject, it is worthy of remark, that the poverty of Scotland in the fossilised bones of Pleistocene Mammalia, and of man or his works, is, doubtless, chiefly due to the general absence in that country of large masses of limestone. There are sea-worn caverns, one known as the cave of Smoo, in the Durness Limestone of Sutherlandshire; while in Assynt a bone-cave has been discovered, and from it Messrs. Peach and Horne have obtained remains of Birds, and of the Brown Bear.

One of the earliest caves investigated was that of Kirkdale, near Kirkby Moorside in Yorkshire, situated in the Corallian Limestones. There Dr. Buckland found many bones which had been dragged in and gnawed by Hyænas.

The Victoria Cave, near Settle in Yorkshire, is entered at the base of a Scar in the Carboniferous Limestone, at a height of about 1,450 feet above the sea. It has been carefully investigated by Mr. R. H. Tiddeman. The mouth of the cave was at first much obscured by talus, and when this was removed, a layer was found inside the cavern, partly composed of charcoal and burnt bones. It was on this layer that the original discoverer of the cavern, Mr. Jackson of Settle, found, in 1838, coins, iron spearheads, brooches, and many other articles, all pointing to the fact that the cave had been tenanted during, or not long after, the Roman occupation of Britain. Lower down there lies partly at the entrance of the cavern an accumulation of angular stones, about six feet thick, at the base of which, resting on grey clay, there occurred charcoal, a bone bead, flint flakes, and broken bones of the Brown Bear, and *Bos longifrons* (Celtic shorthorn). Beneath these comparatively modern deposits at the entrance of the cave, and at the base of the talus there was found Boulder-clay, charged with ice-scratched stones and boulders, and this lies upon the edges of deposits of grey clay, and a lower reddish cave-earth. The local absence of Boulder-clay on the ground at the top of the cliff shows that the material could not have fallen from above before the accumulation of the angular débris or talus, called 'screes.' In the lower cave-earth there were found remains of the Hyæna, Grisly Bear, Brown Bear, *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus*, &c.

Other important caverns have been explored in the Magnesian Limestone of Creswell Crags in Derbyshire; in the Carboniferous Limestone of the Vale of Clwyd, and in the promontory of Gower in South Wales. At Cae Gwyn, in the Vale of Clwyd, many Pleistocene Mammalia have been obtained by Dr. Hicks and Mr. E. B. Luxmoore, and these were sealed up in a deposit that occurred beneath the Boulder-clay of the district.

On the south side of the Mendip Hills, about a mile and a half north-west of Wells, there is a hyæna-den near the great cavern known as Wookey Hole. This den is a fissure that had been hollowed out in the Dolomitic Conglomerate, which in so many places fringes, like an old beach, the Carboniferous Limestone. This cave was systematically explored by Professor Boyd Dawkins, Mr. James Parker, and others; and they obtained upwards of 3,000 bones of mammalia, together with Palæolithic implements.

Again in Devonshire, at Kent's Hole, near Torquay, there is one of the most famous caverns, studied and written about, between 1836 and 1840, by the Rev. John McEnery, who at that early date obtained remains of many of the mammalia, recognised that some of the bones had been gnawed, and what is most remarkable, insisted on the fact that flint implements occurred in intimate association with the bones. The subsequent long-continued and enthusiastic researches of Pengelly amply confirmed these views.

Another important cavern is that of Brixham, in the Devonian Limestone that forms the south side of Tor Bay. It was discovered in 1858, and Pengelly at once saw the necessity of securing the right of exploration, so as to ensure the most accurate possible examination of its contents and the mode of their occurrence.

In part of the cave, which has many ramifications, the section of the strata was subsequently proved to be as follows:

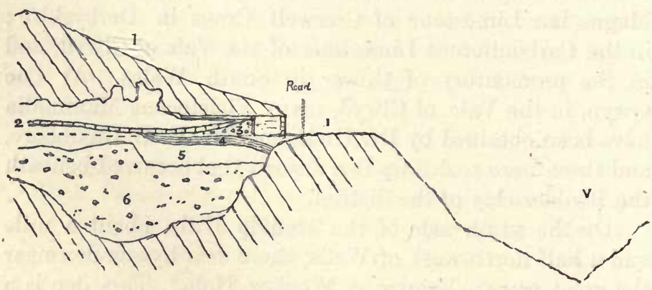


Fig. 2.—Brixham Cave, Devonshire.

3. Breccia.
2. Stalagmite.
1. Devonian Limestone.
V. Valley.
6. Shingle.
5. Cave-earth.
4. Black bed.

The cave is about 66 feet above the bottom of the valley V. Mammalian remains were found sparingly in the stalagmite, No. 2, in abundance in the cave-earth, No. 5, and rarely in the shingle, No. 6. They are of the following species: *Elephas primigenius* (Mammoth), *Rhinoceros antiquitatis* (Woolly Rhinoceros), *Equus caballus* (common Horse), *Bos primigenius*, *Cervus elaphus* (Red Deer), *Rangifer tarandus* (Reindeer), *Capreolus caprea* (Goat), *Felis leo* (Lion), *Hyæna spelæa*, *Ursus spelæus*, *U. horribilis* (Grisly Bear), *U. arctos* (Brown Bear), &c. As in some other cases, previously mentioned, the cave was sometimes a Hyæna-den, for the bones bear the marks of their teeth. With regard to the traces of man, not a single human bone was found; but rude flint implements and chips, referable to man's workmanship, were met with in different parts of the cave; many of them underlying deposits with bones of the Mammoth, Rhinoceros, Hyæna, &c. The implements were of undoubted early palæolithic type, more or less similar to Fig. 100, p. 291.

Quite recently a fissure in the Kentish Rag at Ightham, in Kent, has been found by Mr. W. J. Lewis Abbott to be remarkably fossiliferous. No less than forty-eight different forms of vertebrates have been identified by Mr. E. T. Newton, among several thousand bones that were obtained. These include Mammoth, Rhinoceros, Hyæna, Reindeer, and many small Mammals, as well as Birds, Reptiles, and Amphibians.

Mammalian remains and works of man are also found in various alluvial deposits in our river-valleys, and to these attention will be drawn in the next chapter.

CHAPTER XXVI.

PLEISTOCENE AND RECENT EPOCHS: — OLDER RIVER DEPOSITS, AND THEIR RELATION TO THE GLACIAL DRIFTS—PALÆOLITHIC IMPLEMENTS—RECENT ALLUVIA—NEOLITHIC IMPLEMENTS.

It may be safely said that before the Glacial period the larger features of the river systems of Britain were much the same as now. Some valleys, however, were very much modified; some, indeed, were deepened during the Glacial period; and all have been more or less modified since that period came to an end. When Boulder-clay overspread great part of the country, the river channels of the lower lands often got filled with that clay entirely, or in part. When the land emerged and surface drainage was restored, most of the rivers followed their old channels. In some cases they nearly scooped the Boulder-clay entirely out of them from end to end, but in others, as with the Tyne and the Wear, accidents partly turned the rivers aside, and having disposed of a thin covering of Boulder-clay, they proceeded to excavate deep and winding valleys in the Sandstone rocks below. This may be well seen at Durham on the Wear, where, according to Mr. H. H. Howell, the pre-Glacial valley runs nearly north and south from Durham to Newcastle. Thus the river Wear, instead of following this old valley, meanders about, winding in and out of it. At Chester-le-Street, halfway between Durham and Newcastle, the river leaves the course of the old valley altogether, and, turning to the east, makes its way to the sea at Sunderland, passing principally through the Coal-measures, and cutting through the Magnesian Limestone just before entering the sea.

It is for this reason that coal-miners in Northumberland and Durham, while mining a bed of coal, sometimes find it crop up deep underground against a mass of Boulder-clay that fills an ancient rocky valley, of which the plain above gives no indication (Fig. 93).

Again, if we examine the channels of other rivers in the east of England, we find that in places the Ouse, and its tributaries in Bedfordshire, and also many other streams flow through areas covered with Boulder-clay, and have cut themselves channels through it in such a way as to lead to the inference that parts of the valleys in which they

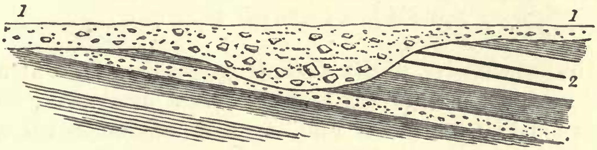


Fig. 93.—Pre-Glacial Valley.
1. Boulder-clay filling a valley. 2. Coal-measures with beds of coal.

run did not exist before the Glacial period, but that they have formed a new system of valleys. This often applies only to parts of their channels which here and there may follow old lines of drainage; thus Mr. Whitaker has described a deep channel of Drift in the valley of the Cam, at Littlebury, in Essex.

Again, with regard to the Thames, it is remarkable that it cuts right across the escarpment of Chalk, for, as explained in Chapter XXXI., this escarpment dates from long before the deposition of the Boulder-clay. The phenomena, taken as a whole, certainly show that the upper course of the Thames is of older date than the Glacial epoch. Therefore I see no reason why the lower valley of the Thames west and east of London should not be pre-Glacial, in which case it may be that some of its high-level gravel-terraces belong to that date. The question is still in debate among geologists; although the discovery of Boulder-clay near Hornchurch (see p. 243) shows that there the higher gravels are newer than that Glacial Drift. The term high-level gravels is used to express the fact that after thick deposits of gravel and loam had been formed in the valley, they were subsequently cut into a succession of river-terraces in consequence of changes,

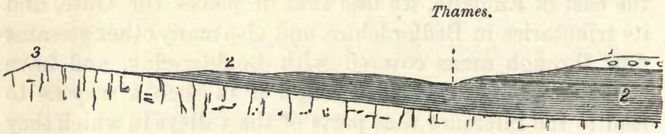


FIG. 94.—SECTION ACROSS THE THAMES VALLEY IN ESSEX AND KENT.
1. Boulder-clay. 2. London Clay, &c. 3. Chalk.

slight but effective, in the physical geography of the area; and it is obvious that the highest terrace overlooking the river must be the oldest, and so on in succession till we reach the river-bank of to-day.

It is now desirable to explain the manner in which rivers have excavated their own valleys in solid rocks where no valleys existed before the drainage of the country took the general direction of its present flow. Suppose a river flowing in a sinuous channel in the direction in which the arrows point in the following diagram:—

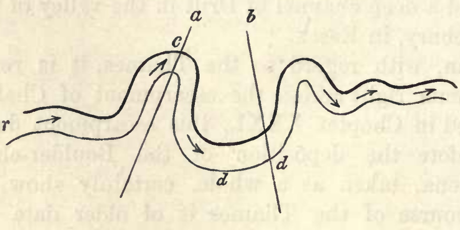
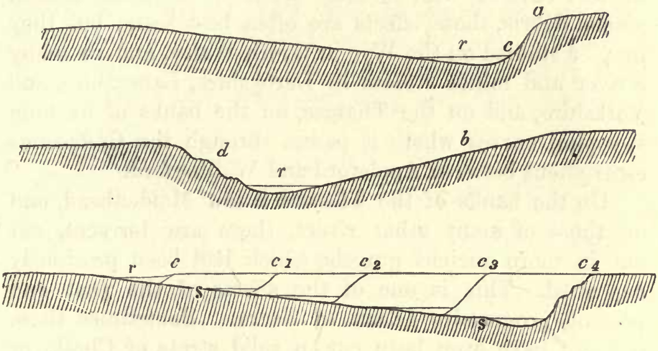


FIG. 95.—PLAN OF RIVER COURSE.

If the banks be high, they almost always have the shape shown in the section lines *a* and *b* across two of the greater curves of the river. The water rushing on is projected with great force against the concave part of the curve, *c*, Fig. 96, and in like manner it is again strongly projected against the concave cliff, *d*, Fig. 97. The result is, that the water wears back the cliffs, *c* and *d*; or, what tends to the same end, in conjunction with the wearing action of the water, the débris, loosened by atmospheric causes on the steep slopes, *c* and *d*, readily slips down to the level of



FIGS. 96, 97, 98.—SECTIONS ACROSS A RIVER VALLEY.

the river, and is carried away by the force of the stream, thus making room for further slips.

When we think of the meaning of this, it at once explains the whole history of these constantly recurring forms, in all winding rivers that flow between cliffs or banks higher than the broad alluvial plains and deltas. Take the history of the curve, Fig. 95, as an example. On a high tableland the river, *r*, at an early period of its history, flowed where it is marked in Fig. 98 the beginning of the curve, *c*, Fig. 95, having already been established, but without any high cliffs. Then the stream, being driven with force against the concave curve, *c*, by degrees cut it back, we shall suppose, to c^1, at the same time deepening its channel. A cliff was thus commenced at c^1, and, as the river changed its bed by constant encroachment in the same direction, a gentle slope, *s*, began to be established, facing the cliff c^1, and so, on and on, through long ages, to c^2, c^3, and c^4, where the present cliff stands, itself as temporary as its smaller predecessors. This is the reason why in river-curves, the concave side of the curve is so often opposed by a hard rocky bank, while the convex side so generally presents a long gentle slope, *s s*, often more or less covered with alluvial detritus. In areas free of glacial débris, these effects are often best seen; but they may be studied on the Wye in South Wales, and in many a river and minor stream in Derbyshire, Lancashire, and Yorkshire, and on the Thames, on the banks of its long sweeping curves where it passes through the Cretaceous escarpment between Appleford and Wallingford.

On the banks of the Thames below Maidenhead, and on those of many other rivers, there are terraces, cut out in more ancient gravels, which had been previously deposited. This is one of the effects of the past and present progressive action of rivers. Sometimes these terraces have even been cut in solid strata of Chalk, or London Clay, or in old gravels. Thus, in the diagram (Fig. 99), No. 1 represents the Chalk, covered on the top of the tableland with Glacial Drift, No. 2, these bounding a wide valley partly filled with ancient gravel, No. 3, which originally filled the valley from side to side as high as the uppermost dotted line, 4; but a river flowing through, by degrees bore part of the loose detritus to a lower level, thus cutting out the terraces in succession, marked Nos. 5, 6, and 7. In the case of the Thames Valley-gravels near Maidenhead, much of the material that forms them was obtained ready-made from the Glacial gravels that cap the tablelands.

It often happens, that alluvial and gravelly deposits that sometimes even cap minor hills are left, marking ancient levels of rivers; and in such gravels, sands, and loams, the bones of animals of extinct and living species have been found, together with the Palæolithic handiwork of ancient races of men.

Viewed as a whole, the remains of Mammalia found in these river-beds have been generally believed to be of Post-Glacial age, and this may be the case with regard to some of the rivers. River-deposits, however, may be newer than the Boulder-clay of the district, and yet be older than the later Glacial Drifts. On the Sussex coast at Selsey, estuarine muds, with *Scrobicularia*, and with remains of *Elephas primigenius*, *E. antiquus*, *Rhinoceros*, &c., overlie a Glacial deposit, as before mentioned (p. 245). Numerous Plant-remains have also been found by Mr. C.

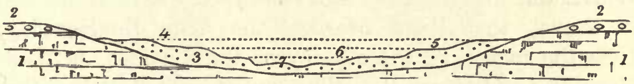


FIG. 99.—SECTION ACROSS A RIVER VALLEY SHOWING TERRACES OF GRAVEL.

2 Glacial Drift. 4, 5, 6, 7. Terraces of Gravel.
1. Chalk. 3. Valley Gravel.

Reid; the fauna and flora indicating temperate conditions during the formation of this mud-deposit. Above these fossiliferous strata lies a stony and chalky loam, known as the 'Coombe Rock,' which indicates a recurrence of Arctic conditions. Here, then, we have evidence of an Interglacial or mild episode; and Mr. Reid, comparing the fossiliferous beds with those of the older Thames Valley deposits, expresses the opinion that some of the widespread sheets of Thames Valley-gravel are of later date, equivalent in age to the Combe Rock, and formed, like that chalky accumulation, by the denudation of frozen land-surfaces. One circumstance is worthy of special remark, that to a great extent the Pleistocene Mammalia in the river-gravels and brick-earths of the southern half of England are identical with the older species found in the British Bone-caves.

They comprise *Felis leo*, *Hyæna spelæa*, *Ursus arctos Hippopotamus amphibius*, *Elephas primigenius*, *E. antiquus*, *Rhinoceros antiquitatis*, *R. leptorhinus*, *Ovibos moschatus*, *Rangifer tarandus*, *Cervus giganteus*, &c. In the same river-deposits many land and fresh water Mollusca are found, including *Corbicula fluminalis* and *Unio littoralis* no longer living in Britain.

In the neighbourhood of Bedford, on the Ouse, there are beds of river-gravel which rise about twenty-five feet above the level of the river, in broad terraces ; and in one of these, well above the river, there have been found a considerable number of flint implements, associated with bones of the Mammoth and other Mammalia. On the borders of Norfolk and Suffolk, at Hoxne near Diss, remarkable discoveries of flint implements have been made in gravel, that there overlies the main Boulder-clay. Near the mouth of the estuary of the Thames, between Reculvers and Herne Bay, flint implements of Palæolithic type have been obtained from the high-level river-gravel (see Fig. 100). In many places further up the Thames, the remains of extinct Mammalia have been found : as at Crayford, Ilford, London, Acton, Ealing, and other places. In some of these localities Palæolithic implements have also been found.[1]

Westwards, in the Axe valley in Devonshire, a number of Palæolithic implements, fashioned out of Greensand chert, have been discovered in the valley-gravels ; and these gravels also yield remains of Mammoth. As yet, however, the bones of Man have rarely been discovered along with extinct Mammals in British river-gravels. Near Bury St. Edmunds, however, Mr. H. Prigg obtained portions of a human skull in brick-earth that yielded Palæolithic implements.

Though it cannot be proved to a demonstration that man inhabited our area in Pre-Glacial times, yet the con-

[1] See *Ancient Stone Implements, &c., of Great Britain*, by Sir John Evans, 1872.

currence of probabilities that he did so is so great, that I have a profound conviction that, at that epoch, here he must

FIG. 100.—PALÆOLITHIC IMPLEMENT, HERNE BAY.
In the Museum of Practical Geology.

have been. Implements of a rude Palæolithic type have been obtained by Mr. Benjamin Harrison on the plateaux of Kent; they seem to be of an earlier type than those found in the river-gravels, but their higher antiquity has yet to be proved. It seems to me probable that man did live here before the Glacial epoch began, and that he retired to the south before the advancing ice-sheets. The changing climate might by degrees suit him well enough, for do not the Greenlanders of our own time live in comfort in their own way among and on the edges of the snows and glaciers of Greenland? Ethnologically, Professor Boyd Dawkins, in 'Cave Hunting,' has compared them to our own Palæolithic men. If in Britain such men survived the Glacial epoch, their blood, much diluted, may even still be among us.[1]

There is, of course, plenty of evidence that some of the Alluvial deposits of the Thames and of all other rivers are altogether Post-Glacial, and the history of these Alluvia can often be traced down to historical times, by means of their organic remains, and of various works of man found in the deposits.

Among the Recent Alluvia we include the peats and broad marshy deposits of the Fenland, the *warps* of the Humber, the Somersetshire levels, such as Sedgemoor, and the flat marsh-lands that fringe our rivers, especially those in the lower courses of the Severn, and the Essex flats that border the Thames.

These deposits consist of loam, silt, peat, shell-marl, and gravel, in fact all kinds of material: due in part to the wasting action of the rivers, sometimes working on the Boulder-clays or Gravels, and sometimes partly wearing out new valleys, and when flooded spreading sediments abroad on the low lands. As in the older alluvia, so in these more recent deposits, it is natural that many bones of Mammalia should be found, a few of which may be of extinct species. Thus in the Recent, as distinct from the Pleistocene, Alluvial deposits, we find remains of *Bos longifrons*, *Capra hircus* (Goat), *Cervus alces* (Moose), as well as the Brown Bear, Wolf, Reindeer, &c., which occur

[1] See also W. G. Smith, *Man, the Primeval Savage*, 1894; and Dawkins, *Early Man in Britain*, 1880.

also in the older deposits. The Mammoth is not found, and instead of Palæolithic implements, we find those of Neolithic type, and also implements of Bronze and Iron.

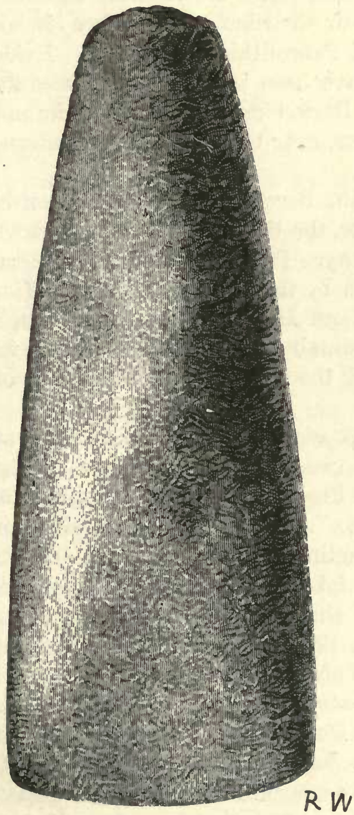


FIG. 101.—NEOLITHIC HATCHET OR CELT.
Dredged from the bed of the Thames, Erith; now in the Museum of Practical Geology.

Implements of Neolithic age (Fig. 101), as remarked by Prof. J. Geikie, occur everywhere throughout the British Islands. 'From Caithness to Cornwall, and from the east coast of England to the western borders of Ireland, they are being continually picked up. Even in the bleak Orkney and Shetland Islands, and all over the Inner and Outer Hebrides, relics of neolithic times have been met with.'[1] Their distribution therefore is wide, compared with that of Palæolithic implements. Evidences of lake-dwellings have been met with in meres at Wretham in Norfolk, at Barton near Bury St. Edmunds, at Ulrome in Holderness, near Glastonbury in Somerset, and also in Scotland.

Among the Recent Deposits the extensive peat-moors of Sedgemoor, the Fenland, and the borders of the Solway, are noteworthy. Peat is formed in more or less stagnant marshy areas by the growth and decay of various Mosses (*Sphagnum* and *Hypnum*), Rushes, Reeds, Sedges, Ferns, &c. On mountains the growth of peat is favoured by the dampness of the air; it is there formed of Mosses and Heather.

Where the sea has encroached on the peaty Alluvium of river-valleys, we often find evidence of what are termed 'Submerged Forests,' and these sometimes afford evidence of depression. A light siliceous deposit, known as Diatom-earth, is sometimes found in Alluvial deposits, along river-valleys or in lakes. It is composed mainly of the siliceous structures of Diatomaceæ. Deposits have been found here and there in Scotland, and in the Isle of Skye. Beds of calcareous Tufa or Travertine are also of interest, as in them numerous Plant-remains, Mollusca, &c., may be preserved. At Dursley, in Gloucestershire, tufa has been quarried for building-purposes; portions of old Berkeley Castle were constructed from it. Deposits of this nature are formed by springs that issue from limestone strata.

[1] *Great Ice Age*, ed. 2, p. 530.

CHAPTER XXVII.

PLEISTOCENE AND RECENT EPOCHS :—RAISED BEACHES—BLOWN SAND—MODERN COAST EROSION.

MENTION has been made of those changes of level indicated by Submerged Forests; more striking, perhaps, are the proofs of upheaval in Post-Tertiary times. Round great part of our coast we find terraces from twenty to fifty feet above the level of the sea, and in some places the terrace runs with persistence for a number of miles. Round the Firth of Forth, for example, on both shores, there is an old sea-cliff of solid rock, overlooking a raised beach or terrace, now often cultivated, and then we come to the present sea-beach. This terrace usually consists of gravel and sea-shells, of the same species as those that lie upon the present beach, where the tide rises and falls. The same kind of terrace is found on the shores of the Firth of Clyde, and round the Isle of Arran, and in almost all the other estuaries of Scotland, and in places round the coast of the West Highlands, as near Oban and Strome Ferry. Old sea caverns are common in these elevated cliffs, made at a time when they were daily washed by the waves. Similar or analogous raised beaches occur on the borders of Wales, and in the south of England. In Devon and Cornwall there are the remains of old consolidated beaches clinging to the cliffs from twenty to thirty feet above the level of the sea. It is clear, therefore, that an elevation of the land has occurred in places to the extent of about forty feet, at a very recent period, long after all the living species of shell-fish inhabited our shores. In

Scotland other old sea-terraces occur at heights of a hundred feet and more.

Further, in the alluvial plains that border the Forth, and on the Clyde in the neighbourhood of Glasgow, at various times, in cutting trenches, canals, and other works, the bones of whales, seals, and porpoises, have been found, at a height of from twenty to thirty feet above the level of high-water mark. That part of the country, therefore, must have been covered with salt water, which is now occupied simply by common alluvial detritus. But the story does not stop there, for together with the bones of the whales in the upraised marine clays of the Forth, implements of bone and wood have been obtained, and in beds on the Clyde, canoes were found in a state of preservation so perfect that their form and structure could be well made out.

The former encroachments of the sea over areas from which it is now barred are shown in the shelly sands of Burtle and other places in the Somersetshire levels.

While considering modern accumulations, those great heaps of Blown Sand that fringe many portions of our coast may be mentioned. On flat shores, where great expanses of sand are exposed at low tide, the wind raises great hillocks or 'dunes' of sand, which sometimes stretch some way inland, and have at times overwhelmed cultivated and inhabited tracts. The outlines of these sand-hills, when seen from a distance against the sky, are of a mountainous character, though they rarely rise above eighty feet. Among the more important tracts are those of the Culbin Sands, on the coast near Forres, which overwhelmed one of the most fertile portions of the old province of Moray. Again, we find tracts along the Dornoch Firth, and in the far north of Scotland near Durness, and in the Outer Hebrides. To the south, in Wigtonshire, at the head of Luce Bay, there are considerable areas of Blown Sand. In England the 'links' of the Northumberland coast, and the 'meals' of the Norfolk coast, are well known. A great sand-flood occurred in 1668 at Santon (*Sand town*) Downham between Brandon and Thetford. Again, in Cornwall, the Church of St. Piranus, Perranzabulo (or *Perran in sabulo*), was for seven centuries smothered in sand, until opened up in 1835. In Devonshire at Braunton Burrows, in Somerset at Burnham, in Glamorganshire at Candleston Castle, and along the Lancashire and Cumberland coasts, there are noteworthy accumulations of Blown Sand. These sometimes enclose land-shells and other organic remains, and various antiquities dating from Neolithic to modern times.

Other modern changes have taken place in the waste of the coasts. Thus south of Flamborough Head in Yorkshire, in the district called Holderness, many towns, long ago built upon the coast, have been forced by degrees to migrate landwards because of the encroachment of the sea. The whole area on which Ravenspur stood, once an important town in Yorkshire, where Bolingbroke, afterwards Henry IV., landed in 1399, is now fairly out at sea. The same may be said of many another town and farmstead, and the sea is ever muddy with the wasting of the land. In like manner, all the soft coast-cliffs, from the Humber to the mouth of the Thames, are suffering similar destruction in places at an average rate of from two to four yards a year. The Norfolk coast near Cromer, and further south, is wasting away at a rate estimated by Mr. Reid as probably not less than two yards a year. The strata consist of boulder-clay and soft sands and gravels. The cliffs are often lofty, rising in places to 200 feet, and vast landslips are of frequent occurrence along the shore, where the restless waves rapidly dispose of the material. High up on the edges of the cliff we see the relics of old brick-built wells, that once belonged to vanished farmhouses; and strongly-built tunnels, now in ruins, that descended to the sea, and were once used by fishermen, gape high on the cliffs, themselves a greater ruin. One notable example is found at Eccles-by-the-Sea, in Norfolk. The encroachments have been so great, that the body of the church has been destroyed, though the tower still stands on the foreshore.

On the south side of the estuary of the Thames stands the ruined church of Reculvers, on a low hill of Thanet Sand, half surrounded on the land side by the relics of a Roman wall, that in old times encircled the little town, then probably at least a mile from the sea. Half the churchyard is gone, while from the cliff the bones of men protrude, and here and there lie upon the beach. A little nearer Herne Bay, the same marine denudation sparingly strews the beach with yet older remains of man, in the shape of Palæolithic flint-weapons, washed from old river-gravels that crown part of the cliff.

In the Isle of Sheppey, great slips are of frequent occurrence from the high cliff of London Clay that overlooks the sea.

Along the southern coast, in Hampshire, and again in Dorset, from St. Aldhelm's Head to Weymouth, and further on from Bridport Harbour to Axmouth, if we walk along the footpaths that are used by coastguardsmen, we often find that the path on the edge of the cliff comes suddenly to an end, and has been re-made inland. This is due to the fact that the cliffs are largely composed of clays overlaid by soft sands and limestones, and every year large masses slip out seaward and are rapidly washed away by the waves.

At Selsey Bill the site of the ancient Saxon Cathedral Church that preceded that of Chichester is known to be far out at sea. In Devonshire, we find the same kind of destruction going on, one remarkable case of which is the great landslip between Lyme Regis and Axmouth, which took place in the year 1839. The strata there consist on the surface of Chalk, underlaid by Upper Greensand, which is underlaid by the Lias Clay. The Chalk is easily penetrated by water, and so is the sand that underlies it: and the sand is apt to be loosened and carried away by springs.

After heavy rains, the water having sunk through the porous beds, the clay beneath became exceedingly slippery, and thus it happened, that the strata dipping seaward at a low angle, a vast mass of Chalk more than half a mile in length slipped forward, forming a grand ruin, the features of which are still constantly changing by the further weathering and foundering of the Chalk and Greensand. In the Undercliff of the Isle of Wight, and near Folkestone, we find other notable instances of landslips; and many have taken place along the slopes of escarpments inland. On the coast, however, such slips largely aid the sea in the destruction of our cliffs.[1] The ruin of the cliffs in one place is sometimes compensated by the increase of land in other places, as at Spurn Head, Yarmouth, and Dunge Ness. The destruction of the New Red pebble-bed of Budleigh Salterton has contributed material to the great Chesil Beach that extends from near Bridport Harbour to Portland.

I know of no place in Britain where the effects of long-continued marine denudation can be better studied than on the coast at St. Bride's Bay, in Pembrokeshire. Let the observer cross to Ramsey Island, opposite St. David's, and ascend one of the rocky hills. Below he will see that a large part of the island forms a portion of an extensive tableland, which is continued far into the mainland of Pembrokeshire, broken only by minor hills formed of hard igneous rocks which have more effectually resisted denudation, while far to the south the islands of Skomer and Skokholm continue the outlines of the upland plain, which is, in fact, similar to an old plain of marine denudation.

On the coast at Watchet, in Somerset, a plain of rock has been formed that extends seaward for some distance at low water. Along the coast formed of Old Red Sandstone near Arbroath in Forfarshire, the broad inland plain ends abruptly in vertical precipices, that rise from

[1] See also Topley, 'On Erosion of Sea-coasts,' *Rep. Brit. Assoc.* or 1885, 1886, &c.

150 to 250 feet above the waves at their base, and while the tide is retreating to its lowest ebb, long reefs and skerries of hard-edged strata tell of the progressive cutting back of a great modern *plain of marine denudation*, similar to that old one which stretches inland from the high edge of the existing cliff.

The Needle-rock near Fishguard, the Needles of the Isle of Wight, Old Harry and his Wife off Ballard Down, the Parson and Clerk near Dawlish, and many other rocky 'stacks' form excellent cases in point, standing a little aloof from the high cliffs of rock that form the shore-line; and the Orkney Islands themselves are only fragments of an older land separated by denudation from the mainland of Scotland. There, too, the 'Old Man of Hoy' is a notable example of a sea-stack. Thus denudations on a great scale are going on now, and when I speak of former unions and separations of our island with and from the mainland by denudation and oscillation of level, the statement is founded on excellent data.

CHAPTER XXVIII.

QUALITIES OF RIVER-WATERS—DISSOLUTION OF LIMESTONE ROCKS.

If we examine the geological structure of our island with regard to its watersheds and river-courses, we find that the larger streams, with one or two exceptions, run into the German Ocean ; the chief exception being the Severn and its tributaries, which drain a large proportion of Wales, and a considerable part of the interior of England. A much larger area of country is, however, drained towards the east than to the west.

When we examine the quality of the waters of our rivers, we find that this necessarily depends on the springs that feed them, and on the nature of the rocks and soils over which they flow.[1] Thus the waters of the rivers of Scotland are, for the most part, soft. All the Highland waters, as a rule, are soft ; the mountains being composed of granitic rocks, gneiss, mica-schist, and the like, a very small proportion of limestone being intermingled therewith, the rocks being, for the most part, almost free from carbonate of lime. Only a small proportion of the carbonates of lime, soda, or potash, is taken up by the water that falls upon and flows over these rocks, the soda or potash being chiefly derived from the felspathic ingredients of the various formations, and therefore the waters are soft. For this reason, at a vast expense, Glasgow has been supplied with water from Loch Katrine, which, lying amid the gneissic rocks, is, like almost all other waters from our

[1] See also *Reports of the Rivers Pollution Commission* 1870-74.

oldest formations, soft, pure, and delightful. The same is the case with the waters that run from the Silurian rocks of the Lammermuir Hills; and the only fault that can be found with all of these waters, excepting by anglers in times of flood, is that they are apt to be a little flavoured and tinged by colouring matter derived from peat.

The water of the streams traversing the grits and slates and igneous rocks of the Cumberland mountains is also soft, and so little of the water of that country rises in the lower plateaux of Carboniferous Limestone that the calcareous rocks scarcely affect their quality.

The water from the Welsh mountains is also in great part soft, the country being formed of Cambrian and Silurian gritty and slaty rocks, that make up the larger part of that country. So sweet and pleasant is the water of Bala Lake, compared with that of the Thames near London, that it has been more than once proposed to lead it all the way for the supply of water for the capital; and the same proposal has been made with regard to the waters of Plinlimmon and the adjacent mountains of Cardiganshire. The water, however, that is now supplied to London is considered of 'a very high standard of excellence and purity.'[1]

When in Wales, and on its borders, we come to the Old Red Sandstone district, the marls are somewhat calcareous, and interstratified with impure concretionary limestones, called cornstones, and the waters are harder. The waters are much harder in the Carboniferous Limestone tracts that sometimes rise into high escarpments round the borders of the great South Wales coal-field, and in Flintshire and Denbighshire.

Again, the waters that flow from the northern part of the Pennine chain, as far south as Clitheroe and Skipton, are apt to be hard, because they drain areas composed partly of Carboniferous Limestone. Still, as a rule, wherever they rise in, and flow through strata formed of Yore-

[1] See *Report of Royal Commission on Metropolitan Water Supply*, 1893, p. 71.

dale shales and sandstones and Millstone Grit, the waters are soft; and this is one reason why so many reservoirs have been constructed in the Millstone Grit regions of Lancashire, Yorkshire, and Derbyshire, for the supply of large towns and cities such as Sheffield, Bradford, Preston, and Liverpool. The waters of the Carboniferous Limestone of Derbyshire are hard. All the rivers that flow over the Permian rocks and New Red Sandstone and Marl, are, as a rule, somewhat hard, a few of them particularly hard from the occurrence of sulphate of lime; and the waters of the Lias, and the Oolitic and the Cretaceous rocks, are of necessity charged with those substances in solution that make water hard, because portions of the Lias and the Oolites are so largely formed of limestones, and the Chalk is almost entirely composed of carbonate of lime.

It thus happens that, as a general rule, most of the rivers that flow into the sea on the eastern and southern shores of England, as far west as the borders of Devonshire, are of hard water. The waters of the Severn are less so, but still they contain a considerable amount of bicarbonate of lime in solution. The waters of the Mersey, the Dee, and the Clwyd, are also somewhat hard, while those that flow westward in Wales are soft and pleasant, and would always be wholesome were it not that some are polluted by the refuse from lead and copper mines.

Before proceeding to other subjects, it is desirable to give some idea of the quantity of salts carried in solution to the sea by the agency of running water. The Bath Old Well yields 126 gallons of water per minute, which is equal to 181,440 gallons per day. There are a number of constituents in this water, such as carbonate of lime, sulphate of lime, sulphate of soda, chlorides of sodium and magnesium ; altogether, with minor constituents, there are 144 grains of salts in solution in every gallon of this water, which is equal to 3,732 lbs. per day, or 608 tons a year. A cubic yard of limestone may be roughly estimated to weigh two tons. If, therefore, these salts were precipitated, compressed, and solidified into the same bulk, and having the same weight, as limestone, we should find the annual discharge of the Bath Old Well capable of forming a column 3 feet square in diameter, and about 912 feet high. There are, however, four thermal springs at Bath, and their united discharge is estimated at about 385,000 gallons daily; so that the foregoing estimate may be doubled. Yet this large amount of solid mineral matter is carried away every year in invisible solution in water which, to the eye, appears perfectly limpid and pure. There are many other saline wells in England, such as those of Cheltenham and Leamington; some yield a very considerable amount of saline matter, as at Woodhall Spa, about 1,500 grains, and Swindon, no less than 2,131 grains per gallon. Numberless other springs, nominally fresh, bring to the surface their proportion of salts in solution. Indeed, it has been shown that all springs contain an appreciable proportion of saline ingredients in solution, varying from about 6 to 30 grains per gallon. This being the case, and rivers being fed by springs that have percolated through the porous rocks, in addition to the water drained from the surface, it is obvious that all rivers must contain various proportions of substances soluble in the rocks, and, indeed, it is known that small quantities of silica and certain metals may also be held in solution.

The presence of large quantities of chloride of sodium and of sulphate of lime may be due to dissolution of beds of rock-salt or gypsum that occur in the New Red rocks. Sea-water, too, may in certain cases have gained access to subterranean reservoirs. Thermal waters no doubt owe their temperatures to the depth from which they rise.

The Thames is a good type of a moderate-sized river, draining a country which, to a great extent, is composed of calcareous rocks, and which embraces a total area of 3,548 square miles. Its principal source is near the western edge of the Oolitic tableland of the Cotteswold Hills, and thence it flows eastward across the Oolitic strata, composed mostly of thick formations of limestone, calcareous sand,

and clay, and it is fed by numerous tributary streams. Then, bending to the south-east, below Oxford, it crosses the Lower Greensand, Gault, and Upper Greensand, all more or less calcareous, and the Chalk, which consists of nearly pure limestone: then it traverses the London Clay and other strata belonging to the great Eocene formations of the London basin. The Thames may therefore be expected to contain not only a certain amount of mineral and other matter in suspension, but substances of various kinds in solution in large quantities; and to those derived from the rocks must be added the impurities from the drainage of the lands and of the villages and towns that border its course between the Thames Head and other sources of the river, and London.

At Teddington Weir, on an average, the daily volume of water that passes seaward amounts to 1,193 millions of gallons; and, upon analysis, it was found that about 18 or 19 grains of saline ingredients occur in solution in each gallon. This is equal to about 500,000 tons of mineral matter in a year: and this amount is chiefly dissolved out of the bulk of the solid rocks and surface soils of the country. Of this quantity, as pointed out by Prof. Prestwich, about two-thirds consist of carbonate of lime, and one-sixth of sulphate of lime; while limited proportions of carbonate of magnesia, sulphates of soda and potash, silica, and traces of iron, alumina, and phosphates constitute the rest.[1]

The flow of the Thames is largely sustained by springs. Thus the rainfall on the porous strata gradually sinks down until arrested by clays or other impervious rocks; and the overflow from the saturated strata escapes along the hill sides in the form of springs.

Water is obtained from shallow wells by sinking through porous strata of sand or gravel or limestone, that rest on clays. The water of deeper wells is often derived from the

[1] Address to Geol. Soc., 1872. See also *Report of Royal Commission on Metropolitan Water Supply*, and Appendices, 1893.

rain that falls on distant hills. Thus water obtained from the Chalk under London has passed underground from the North Downs and the Chiltern Hills, and it is prevented from escaping under London by the thick covering of London Clay. In this way Artesian wells are supplied, for in sinking through impervious beds of clay into porous strata that elsewhere outcrop at the surface, the pent-up water may rise some distance in the shaft or bore-hole, or

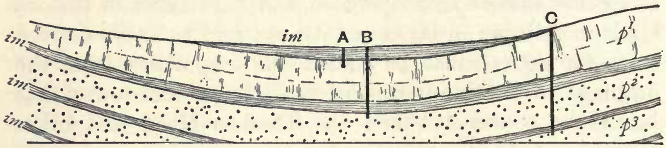


Fig. 102.—Diagram of Artesian Wells. (J. G.)

A, B, C. Wells. *im.* Impervious strata. p^1, p^2, p^3. Porous or water-bearing strata.

overflow at the surface, according to the level of saturation of the natural reservoir of porous rocks (see Fig. 102).

If we consider that the Thames is only one of many rivers that flow over rocks which contain carbonate of lime and other soluble substances, we then begin to comprehend what an enormous quantity of matter by this—to the eye—perfectly imperceptible process, is being constantly carried into the sea. Even in the streams of mountain regions, where the waters are not hard, they yet carry away in solution a large amount of the alkaline and other constituents of the Palæozoic and igneous rocks; and their power is increased by the extra amount of rainfall. Hence, for given areas, the quantity of matter carried to the sea by the western rivers may be approximately equivalent in a year to that which is found in the eastern-flowing rivers. This idea, new to me, was first impressed on my mind by reading the Presidential Address of Mr. T. Mellard Reade to the Liverpool Geological Society, 1876,[1] in which,

[1] Reprinted in *Chemical Denudation in relation to Geological Time*, 1879; see also A. Geikie, 'On Modern Denudation,' *Trans. Geol. Soc. Glasgow*, vol. iii. p. 153.

among other important matters, he states that 'a total of 68,450,936,960 tons of water run off the area of England and Wales annually, equal to 18·3 inches in depth, which leaves 13·7 inches for evaporation.' He estimates the total solids in solution at 8,370,630 tons, and reckoning 15 cubic feet to the ton, he concludes that 'the amount of denudation if distributed equally over England and Wales, reckoned at 58,300 square miles, would be ·0077 of a foot per century, that is, it would take 12,978 years to reduce it one foot.' There is no doubt, however, that the quantity carried away in solution varies much in different geological areas, for of all the rocky formations, limestones are most easily acted upon by the carbonic acid in rain-water.

It is a necessary part of the economy of Nature that this dissolving of the constituents of rocks should be going

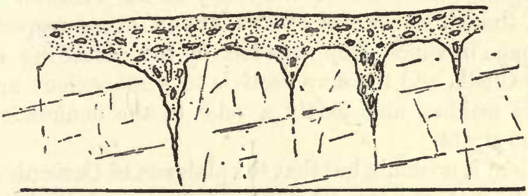


Fig. 103.—Clay-with-Flints, resting in 'Pipes' on the Chalk. (J. G.)

on over all the world, for it is largely from solutions of lime and other mineral matters thus introduced into the sea, that various organisms obtain material for their shells and bones and other structures.

This waste of material by the *dissolving* of rocks is indeed evident over most of the solid limestone districts of England. On the flat tops of the Chalk Downs, for example, over large areas in Dorsetshire, Hampshire, and Wiltshire, quantities of unworn flints, sometimes to a thickness of several feet, cover the surface of the land (see Fig. 103). These accumulations of barren stones have not been transported from a distance, but represent the gradual destruction, by rain and carbonic acid, of a vast thickness of Chalk with layers of flint that once existed above the present surface. The following diagram will explain this :—

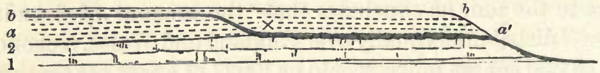


FIG. 104.—SECTION SHOWING EROSION OF THE CHALK.

1, Chalk without flints. 2, Chalk with flints. *a a*, the present surface of the ground marked by a dark line. *b b*, an old surface of ground, marked by a light line. Between *a a* the surface is covered by accumulated flints, the thickness of which is greatest where the line is thickest between *a'* and ×, above which surface a greater proportion of chalk has been dissolved and has disappeared.

An irregular mixture of clay-with-flints, often several feet thick, is also frequent on the surface of the Chalk Downs on both sides of the valley of the Thames. The flints, though sometimes broken, are in other respects of the shape in which they were left by the dissolving away of the Chalk, and the clay itself is to some extent an insoluble residue, and partly a relic of the denudation of Eocene strata.

There is no doubt but that the plateaux of Carboniferous Limestone of the Mendip Hills, of Wales, of Derbyshire, and of the north of England, have suffered waste by solution, equal to that of the Chalk; only we have but little insoluble residue, other than the red earth which occurs in many places, by which to estimate its amount. In Lancashire, north of Morecambe Bay, in Westmoreland, and west Yorkshire, the high plateaux of limestone are often for miles half bare of vegetation, for the earthy residue has been washed away. The surface of the rock is rough and rugged from the effects of rain-water and the carbonic acid it contains. The joints of the rock have in many places been widened by this chemical action, and it requires wary walking, with your eyes on the ground, to avoid, perhaps, a broken leg. The Oolites must have suffered in the same way, especially where not covered by

Boulder-clay; and we find that at the surface they are weathered into a rubble or 'brash.' Rain and rivers are thus the unwearied destroyers of all lands, aided by the restless beating of the waves on rock-bound coasts. These destroy but to reconstruct new strata, by the upheaval of which future lands shall rise.

CHAPTER XXIX.

THE GEOLOGY AND SCENERY OF SCOTLAND:—THE HIGHLANDS—THE GREAT VALLEYS OF THE FORTH AND CLYDE—THE LAMMERMUIR, MOORFOOT, AND CARRICK HILLS.

I NOW come to that part of the subject in which I shall endeavour to explain the connection between the geological phenomena of Britain and the nature of its modern scenery.

In Scotland gneissic rocks and granites are extensively developed. The north-west coast of Sutherland, and the outer Hebrides, chiefly consist of the oldest known formation, formerly called Laurentian, now known as Lewisian. Above them, in Sutherland, unaltered red or purple sandstones and conglomerates (Torridonian), 8,000 or 10,000 feet thick, lie unconformably on the gneiss. The gneiss had assumed its present structure and crystalline condition, and had been much wasted by denudation, before the deposition of the Torridonian strata began, and fragments of the denuded gneiss help to make up the conglomerates. These red sandstones are older than the very oldest fossiliferous rocks in Britain. They are overlain unconformably by quartzites and shales in which Lower Cambrian fossils (*Olenellus*, &c.) have been found, and these strata are conformably covered by a thick mass of fossiliferous limestone, the lower members of which, with the underlying shales and quartzites, can be followed from the north of Sutherland into Skye—a distance of more than 100 miles. Owing to gigantic displacements of the earth's

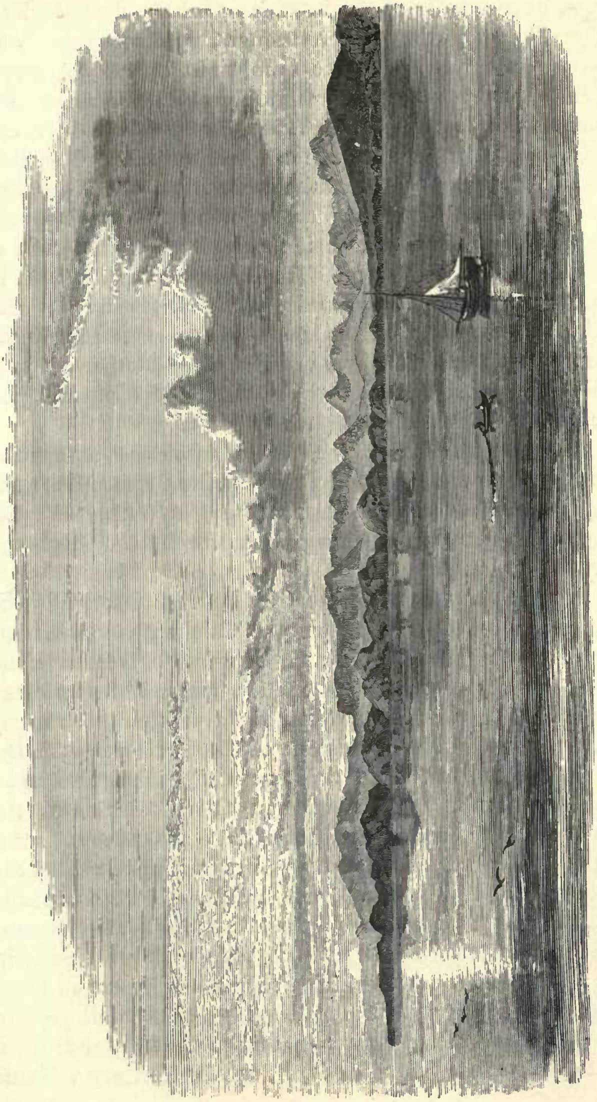


FIG. 105.—MOUNTAINS OF ROSS-SHIRE (TORRIDON SANDSTONE), WITH THE ISLAND OF RONA (LEWISIAN GNEISS) IN FRONT.

crust, huge masses of the Lewisian gneiss and of the Torridon Sandstone have been brought up from below and driven westwards across the Cambrian strata. Subjected to enormous crushing and recrystallisation, the rocks have assumed the characters of various schists, which, in many folds and fractured masses, form the central and eastern parts of the counties of Sutherland, Ross, and Inverness. Similar schists, but often showing distinctly that they were originally sedimentary deposits, form most of the rest of the Highlands of Scotland. The schists are disposed in bands, which have a general north-easterly trend, with which the direction of the Grampian and other hill-ranges corresponds. Huge masses of granite and other eruptive rocks have broken through these rocks, more especially in the central and north-eastern Highlands.

Next, on the north coast, and extending across the centre of the island, we have the Old Red Sandstone; the Upper Silurian rocks, which form such an important part of the English strata, being unknown in the Highland part of Scotland.

Farther south, above the Old Red Sandstone, lie the Carboniferous rocks, consisting of Calciferous Sandstone, Carboniferous Limestone, and Coal-measures, the limestone forming in Scotland but a very small intercalated part of the series. These strata lie in the great valley between the Old Red Sandstone of the Ochil range on the north, and the Old Red Sandstone and Silurian rocks of the Lammermuir, Moorfoot, and Carrick hills, on the south. Besides these formations, there are others in some of the Western Islands, such as Skye and Mull, and in the east and south of Scotland, and elsewhere. These consist of members of the Permian, Trias, Lias, Oolitic, Cretaceous, and Tertiary strata, partly on the mainland but chiefly in the Isles, which, however, form such a small part of Scotland, that only in the Inner Hebrides, on a small part of the mainland at Ardnamurchan, and on the hills of Morven that overlook the Sound of Mull, do the Tertiary volcanic rocks seriously affect its physical geography. Therefore I shall chiefly confine myself to the mainland of the north Highlands, for I wish specially to treat of the facts connected with the greater physical features of Scotland, omitting minor details.

In the extreme north of Scotland, in Sutherland and Caithness, the manner in which the strata generally lie is shown in the following diagram.

FIG. 106.—DIAGRAM-SECTION OF THE ROCKS IN SUTHERLAND AND CAITHNESS.

3. Cambrian rocks.
2. Torridon Sandstone.
1. Lewisian Gneiss.

g. Granitic masses.
5. Old Red Sandstone.
4. Schists (overthust).

I have already mentioned that, in some of the Western Isles, from the Lewes to Barra, and in the north-west of the mainland of Scotland, from Cape Wrath to Gairloch, the country, to a great extent, consists of certain low tracts formed of Lewisian gneiss (Fig. 106, No. 1), twisted and contorted in a remarkable manner. The general characteristic hummocky surface of this most ancient rock of Britain is shown in the island of Rona, as depicted in Fig. 105. Upon this old gneiss the red Torridonian sandstones (2) lie, rising often into mountains, which face the west in bold escarpments, and slope more gently towards the east. These strata frequently lie at low angles very *unconformably* upon the old gneissic rocks; the meaning of this being, that the latter were disturbed, contorted, and extremely denuded, before the deposition of the Torridonian strata that rest upon them. The bottom beds of the latter consist of conglomerates of rounded pebbles, partly derived from the waste of the gneiss, which, therefore, is so old, that it had assumed its existing crystalline form and had been worn into an irregular land-surface before the deposition of the Torridon Sandstones. Upon these still unaltered sandstones, and again quite unconformably, the fossiliferous

Cambrian strata (3) lie, in the manner shown in the diagram ; and conclusions, regarding upheaval and denudation, may be drawn from this second unconformity, similar to those that have been mentioned respecting the unconformity of the Torridonian on the Lewisian rocks. In both is indicated a great interval of time unrepresented by stratified formations. The bottom beds of the Cambrian strata consist of quartzite and dolomitic shales (containing *Olenellus*, &c.), and are followed by the Durness limestones (3). Above the limestone, and brought into that position by the gigantic terrestrial disturbances above referred to, lies a vast series of beds of mica-schist and gneissose rocks (4), mostly flaggy in the north-western region (Moine schists), but, in the eastern parts of Sutherland, often so highly contorted and metamorphosed that they are, in some respects, similar to the more ancient Lewisian gneiss.

Now these schistose rocks, here and there associated with bosses of granite and syenite (*g*), form by far the greater part of that rocky region known as the Highlands of Scotland, which stretches over brown heaths and barren mountain ranges, all the way from Loch Eribol on the north shore, far south across the Grampians, to the Firth of Clyde on the west, and Stonehaven on the east.

In Sutherland, as a whole, the Cambrian strata dip eastward, and in Caithness we have the Old Red Sandstone (5) lying quite unconformably upon the schists and gneiss, and dipping towards the sea. At its base the Old Red Sandstone consists of conglomerate, not formed merely of small pebbles, like those of an ordinary shingle-beach, but frequently of huge masses, suggestive of ice-borne boulders, mingled with others of smaller size. All of them have evidently been derived from the partial destruction of those more ancient gneissic rocks (4) that underlie the Old Red Sandstone.

Again, if we examine the map of Scotland, we find a broad band of Old Red Sandstone running from Stonehaven on the east coast to Dumbarton on the west, and there also masses of conglomerate lie at the base (as in No. 2, Fig. 107). Overlooking this broad band, the Grampian mountains (No. 1) rise high into the air, still reminding the beholder of the ancient line of coast of a vast inland lake, against which the waves of the Old Red Sandstone waters beat. From the waste of the land caused by these waves, aided, in my belief, by glaciers and coast-ice, the boulder-beds that now make part of the conglomerates were formed. We are thus justified in coming to the conclusion that the northern Highlands generally formed land before the time of the Old Red Sandstone. The Grampian mountains were even then separated from the Scandinavian chain, as a special range, forming a long line running from north-east to south-west, the bases of its hills being washed by the waters which deposited the Old Red Sandstone.

What amount of denudation the gneiss and schist mountains of the Highlands underwent, before and during the deposition of the Old Red Sandstone, it is impossible to determine, but it must have been very great. I consider it certain, that from these mountains glaciers descended through ancient valleys, now lost, and indeed that other subangular conglomerates of the Old Red Sandstone in various parts of Britain consist of stratified moraine-matter.[1]

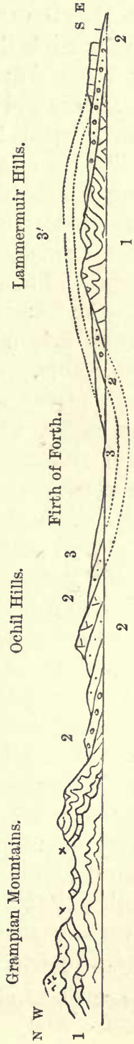


FIG. 107.—SECTION FROM THE GRAMPIANS TO THE LAMMERMUIR HILLS.

1. Various schists with zones of quartzite and bands of crystalline limestone. 2. Old Red Sandstone. 3, 3′. Carboniferous strata.

[[1] The idea that the coarse conglomerates of the Lower Old Red Sandstone have been

All the ordinary influences of terrestrial waste—rain, rivers, frost, snow, ice, wind, and waves—were at work sculpturing the surface of that old land, and on parts of the same land they have been at work from that day to this. What was the precise form of the highlands that bordered this Old Red Sandstone lake, it is now impossible to know, except that it was mountainous; but after the early disturbances of the strata, the general result of all the wasting influences, acting down to the present day, has been to produce the present scenery. Thus it is certain that the Lewisian, Torridonian, and Cambrian rocks of the north-west of Scotland were once buried deep beneath the younger or Eastern gneiss thousands of feet thick, which had been driven over them by powerful disruptions and displacements. On the west the Cambrian strata have been, in places, almost utterly worn away, and the Torridonian rocks, as in Suilven (Fig. 108), have thus been exposed and moulded into outliers by subsequent waste. Some of these mountains of Torridon Sandstone in western Sutherland and Ross-shire now form the grandest and most abrupt peaks of the north-west Highlands, standing, steep-sided and high like Suilven, isolated, on a broad raised platform of Lewisian gneiss. And just as a navigator leaves pillars of earth in a railway-cutting, to mark how much he has removed, so the great agents of Denudation have left these mountain landmarks to record the greatness of their operations.

It is at first hard to realise these facts, but observation and reflection combined prove them to be indubitable.

If we again examine the Map, we find that a large tract of country, forming great part of the *Lowlands*, stretches across Scotland from north-east to south-west, including the Firths of Tay and Forth, and all the southern and eastern shores of the Firth of Clyde. This area is occupied by Old Red Sandstone and rocks of Carboniferous

due to any kind of ice-action has not been generally adopted by geologists.—Ed.]

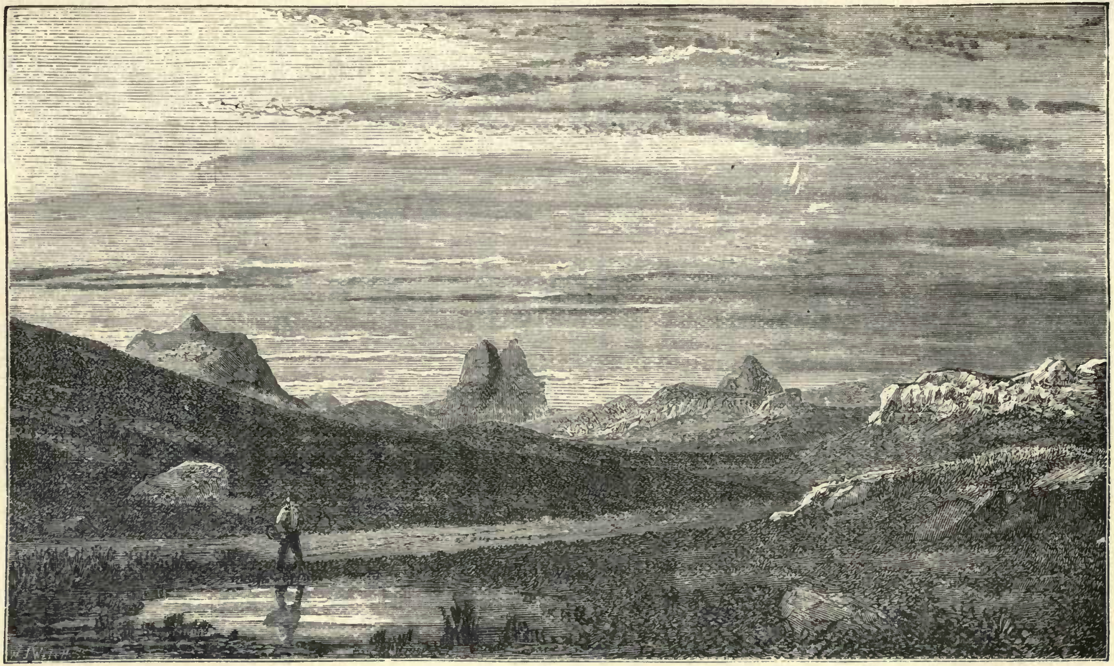


FIG. 108.—VIEW OF COULMORE (2,786 FEET), SUILVEN (2,399), AND CANISP (2,779), SUTHERLAND.
Suilven in the middle of the drawing.

age (Nos. 2 and 3, Fig. 107), mostly stratified, but partly igneous. To the south lies the heathy and pastoral region known as the Southern Uplands or as the Carrick, Lowther, Moorfoot, Pentland, and Lammermuir Hills (1′), which are for the most part formed of Upper and Lower Silurian rocks, much plicated and dislocated. These plunge beneath the Old Red Sandstone, and may, as I believe, rise in places in the Grampian mountains on the north changed into quartz-rock and mica-schist.[1] The unaltered Carboniferous and Old Red Sandstone rocks thus lie, as a whole, in a hollow, between the Grampian and the Lammermuir ranges, the coal-bearing strata consisting chiefly of alternations of shale, sandstone, limestone, and coal, mingled with volcanic products of the period.

In the Scottish area, during the formation of the Old Red Sandstone and Carboniferous formations, many volcanoes were at work; and thus we have dykes, sills and bosses of various kinds of igneous material, together with interstratifications of old lava-streams, and beds of volcanic ashes mingled with common sedimentary strata. These, being usually harder than the sandstones and shales with which they are interbedded, have more strongly resisted denudation, and now stand out in hilly ranges, like the Pentland, Ochil, Campsie, and Garlton Hills, the Renfrewshire and Ayrshire Hills on the Clyde, or in crags and bosses, like Salisbury Crags, Arthur's Seat, Stirling Castle Rock, Dumbarton Rock, the Lomonds of Fife, and many other eminences in central Scotland, which give great diversity to the scenery, without ever rising to the dignity of mountains.

Having thus briefly rehearsed the mode of origin of the more important Scottish formations, we may already begin

[[1] The existence of Lower Silurian radiolarian cherts has recently been ascertained by the Geological Survey on the southern margin of the Highlands. How far Silurian rocks have been involved in the metamorphism that produced the schists of the central Highlands, has still to be determined.]

to perceive what is the cause of the mountainous character of the *Highlands*, and of the softer features of the *Lowlands*. It is briefly this: that, in very ancient geological times, before the deposition of the Old Red Sandstone, the schistose rocks, which form almost entirely the northern half of Scotland, had already been raised high into the air, metamorphosed, and greatly disturbed. Such metamorphic rocks, though, as a whole, difficult of destruction, yet consist of intermingled masses of different degrees of hardness, whence the great variety of their outlines is the result of the softer rocks having been more easily worn away. In the south of Scotland, from Galloway to the coast of Berwickshire, the Silurian strata, forming the Southern Uplands, have been likewise greatly disturbed, though perhaps not originally raised to the same height, but not having been much metamorphosed, they are generally somewhat less hard, and have therefore been more wasted by denudation, whence their average lower elevation. Though the mountains of these southern Highlands cannot compare in height with those of the north, they are sometimes both striking and picturesque in outline, especially where they have been indurated or changed into mica-schist and other metamorphic rocks around great bosses of granite in Wigtonshire and Kirkcudbrightshire.

Nothing can be more impressive, in its way, than the noble amphitheatre of hills that surround the sombre moorland basins of Loch Doon, Loch Finlas, and the smaller lakes and tarns that lie further south and west of the Rhinns of Kells, the highest granitic peak of which has an elevation of 2,668 feet above the sea. Magnitude is not always essential to grandeur, and as in human, so in nature's architecture, proportion of parts often strikes the mind with a sense of majesty which is wanting in larger bulks.

If we take the area of these Southern Uplands, it amounts to about 6,000 square miles, in which the greater hills vary from 1,300 to 2,764 feet in height. In the whole district, more than half the area is under 1,000 feet in height, by far the larger part of the remainder between 1,000 and 2,000 feet; and all the remainder, above 2,000 and under 2,764 feet, occupies a small area of about 75 square miles.

If we turn to the true Scottish Highlands, we find a great many mountains the heights of which exceed 3,000 feet.[1] If we take the whole area of the Highlands, between the Great Glen and the south-eastern slope of the Grampian Mountains, it appears that not one-third of the country is more than 500 feet above the sea, of the remainder less than a quarter ranges between 500 and 1,000 feet in height, while of the rest a large part ranges between 1,000 and 2,000 feet; and after that, about as much remains between 2,000 and 4,406 feet in height, as would cover half the area of the Silurian hills, of the Southern Uplands, between Berwickshire and Wigtonshire.

Beyond Glen More and the Caledonian Canal, as far as the north coast of Scotland, the Highlands have the same general character, though the amount of ground above 2,000 feet in height is comparatively less in the total area, and this amount gradually decreases in proportion the further north we go. Fig. 106, page 313, gives an idea of the general contours in north Sutherland. There, on the flanks of the mountains in Caithness, the Old Red Sandstone, lying in comparatively flat strata, forms an undulating plain consisting of conglomerates on the west, and chiefly of sandstones and flagstones, eastward to Sinclair Bay, where it passes under the sea, while further south,

[1] The following heights may be useful. In Sutherland, Ben Klibreck 3,154 feet, Ben Hope 3,040, Ben More 3,273. In Ross-shire, Ben Dearg 3,547, Ben Wyvis 3,429, and Sleugach 3,217. In Inverness-shire, Ben Attow 3,383, Mam Soul 3,862, Scuir na Lapaich 3,773, Ben Screel 3,196. South and south-east of the string of lakes in the Great Glen, of which Loch Ness is one, there are Ben Vorlich 3,224, Ben Lomond 3,192, Glas Meall 3,502, Ben Dearg 3,304, Ben Lawers 3,984, Cairn Gorm 4,084, Ben Mac Dhui 4,296, and Ben Nevis 4,406.

between Noss Head and Berriedale, high cliffs border the coast.

South of Helmsdale, Old Red Conglomerates and Sandstones skirt the older rocks, crossing the Firths of Dornoch, Cromarty, Beauly, Inverness, and Moray, and stretching south to the noble mountain of Mealfourvounie, 2,284 feet in height, whence, crossing Loch Ness, the beds skirt the country in a broad band beyond the mouth of the Spey. In all this area a large part of the strata consists of conglomerate, and where this rock occurs, because of its occasional hardness, and the very considerable disturbance of the rocks, much of the country ranges between 800 and nearly 1,500 feet in height. In no part of Scotland that I know, are the conglomerates (made of the waste of the older schistose mountains) more striking than in this region, and the glacial origin of some of them to my mind is unmistakable, especially on the shores of the Beauly Firth, near Drynie. The same evidence of ice-work is strikingly shown in the Old Red Conglomerate south of Dunbar. All the embedded stones have been derived from the schists and granites of the neighbouring mountains. Some of them are from four to five feet in diameter, and many are subangular in shape, just like the boulders in much of the detritus of the Glacial epoch.

In time, the Old Red Sandstone period came to an end, and above that series—for it consists of two members, the upper member of which lies *unconformably* on the lower—the Carboniferous rocks were formed. The whole were then again disturbed together—a disturbance not confined to Scotland only, but embracing large European and other areas.

But before the deposition of the Old Red and Carboniferous series, there is reason to believe that a wide and deep valley already existed between the Grampian mountains and the Carrick, Lammermuir, and Moorfoot range; and in this hollow the Old Red Sandstone was deposited, mainly, no doubt, derived from the waste of the hills on the north and south. But by-and-by, as deposition progressed, the land began to sink on the south, and the upper strata of Old Red Sandstone overlapped the lower beds, and began, as it were, to creep southwards across the Lammermuir Hills, which, sinking still further, were in turn invaded by the Carboniferous Limestone series. It appears, indeed, from a consideration of all the circumstances connected with the physical relations of the strata, that the Coal-measures not impossibly once spread right across the Lammermuir range, and were united to the Carboniferous strata that now occupy the north of England, thus, with much of the Old Red Sandstone, covering great part of the Silurian strata of the south of Scotland. This unconformable covering has, however, in the course of repeated denudations, been removed from the greater part of that high area, and now the Carboniferous strata are only found in the depressions on either side of the Uplands.

This will be easily understood by referring to Fig. 107, in which the following relations of the various formations are shown.

The schistose, granitic and other rocks of the Grampian mountains (No. 1), with bands of limestone marked +, pass under the Old Red Sandstone (No. 2). On the south side of the great basin of the central counties, Silurian rocks (1′) emerge, on which the lower conglomerates of the Old Red Sandstone (No. 2) lie unconformably. Adjoining and overlying these, a series of red sandstones, conglomerates, flagstones, and shales, occupies the broad tract of comparatively low ground which stretches from the base of the Highland mountains to the Firth of Tay, and westwards in a narrowing belt to Loch Lomond and the Clyde. One of the most marked features of this series of strata is the occurrence in it of thick sheets of volcanic lavas, ashy breccias, and conglomerates of a volcanic nature. These intercalations in the chain of the Sidlaw Hills dip towards the north-west; on the opposite side of the Firth of Tay, in the continuation of the chain of the Ochil Hills, they dip to the south-east. Being harder than their associated sandstones, they form high escarpments, the steep-scarped front of which, on the north side of the Tay estuary, faces to the south-east, and on the south side to the north-west, in accordance with a law that, on a great scale, rules the mode of formation of such slopes; the more gentle inclines being in the direction of the dip, and the steep scarp sloping at right angles to the average inclination of the strata (see Fig. 107, p. 315).

Let anyone who wishes to see this effect walk to the summit of the Ochil Hills, and there, from the edge of the scarp, he will see in the main a gentle slope to the south-east, while below, on the north-west, the delighted eye ranges across the fertile plains and undulations of the Teith, Strath Allan, and Strath Earn, while, far beyond, this almost unrivalled view is bounded by the lofty chain of the Grampian mountains. Let the reader also understand that the Lower Old Red Sandstone of the plain that surrounds the estuary of the Tay was once buried deep under the volcanic series, and he will then begin to realise the prodigious amount of denudation that the region has suffered before it assumed its present aspect.

Above and merging into the Old Red Sandstone come the Carboniferous rocks No. 3, Fig. 107, lying in a wide faulted and denuded synclinal curve,[1] but with many a high boss of basalt standing out in bold relief in the midst. Such protruding knobs of igneous rock form the Lomonds of Fife, and Largo Law, while south of the Forth, Arthur's Seat, North Berwick Law and the Bass Rock are well-known examples. The pastoral tract of the Pentland Hills, which consists of volcanic materials belonging to the same Lower Old Red Sandstone series as the Ochil and Sidlaw Hills, stands in high relief above the fertile Carboniferous plains of Midlothian.

I have already stated that the southern continuation of the Upper Old Red Sandstone and Carboniferous strata once spread over the Lammermuir Hills in a kind of anti-

[1] The diagram is, however, too small to show these faults.

clinal curve, in the manner shown by the dotted lines No. 3′, on the diagram Fig. 107.

Now why is it that the Carboniferous and Old Red Sandstone rocks have been specially preserved in the great valley, and almost entirely removed from the Southern Uplands? The reason is this: When strata have been thrown into a series of anticlinal and synclinal curves, it has frequently happened that those parts of the disturbed strata that were thrown downwards, so as to form deep basin-shaped hollows, were by this means partly saved, for long periods of time, from the effects of denudation; while the upper parts of the neighbouring anticlinal curvatures, being exposed to all the wasting influences of the air, rain, rivers, and the sea, were denuded away.

In other words, some widely extended portions of the strata lay so deep that no wasting influence had access to them, and they have escaped denudation, and the basin—as geologists term it—remains. This is the reason why so many coal-fields lie in basins. Such basins are common to all kinds of formations; though, because they rarely contain substances of economic value, they have not met with the same attention that Coal-basins have received.

In the case now under review, Old Red Sandstone and Carboniferous rocks lie in the hollow. Though much worn away, they have been to a great extent preserved; while the continuation of part of the same formations that lay high in an anticlinal form, and originally spread over the Lammermuir Hills (3′), has been almost all removed by denudation. The reason of this is, that during frequent oscillations of land, relatively to the level of the sea, the higher ground was much more often above water than the lower part, and was, therefore, far oftener and more continuously exposed to waste and destruction. To understand this thoroughly, let us suppose that the whole of the formations now forming this area lay, in an ancient epoch, underneath the sea. Let us further suppose that certain tracts of the area including the site of the Lammermuir

Hills were raised, more or less above sea-level, well into the air. The ground which ultimately became the Lammermuir Hills, then covered by Old Red Sandstone and Coal-measures, as soon as it rose above the water, would be subjected to the wear and tear of breakers on the shore, and of rain, rivers, frost, and other atmospheric influences; while, on the other hand, that portion of the area that lay deep in the synclinal curve was beneath the level of the sea, and thus escaped denudation, because no wasting action takes place in such a situation.

By geological *accidents* such as these, the greater features of Scottish scenery have been produced. The Highlands are mountainous because they are composed of rocks much disturbed, metamorphosed, and mostly crystalline, and intermingled with great and small bosses of hard granite. The areas of Cairn Gorm and Ben Mac Dhui, of Ben Cruachan, and of Goat Fell in Arran, are granite; while Ben Nevis is formed of the same rock with a core of porphyrite. All of these rocks having been often and long above water, have been extremely denuded: such denudations having commenced so long ago, that they date from before the time of that extremely venerable formation, the Old Red Sandstone, probably indeed ever since what, for want of better words, we term the close of the Lower Silurian epoch, and the waste has been going on, more or less, down to the present day.

Being formed for the most part of materials of great but unequal hardness, and associated with masses of granite, the high land has been cut up into innumerable valleys by the repeated action of rain, rivers, and glaciers, whence their irregular and rugged character. The special outlines of mountains, as we now see them, are rugged, less from disturbances of strata than from the scooping away of material. By mere elevation and disturbance of strata, the land might rise high enough; but as mountain regions now exist, it is by a combination of disturbance of strata with extreme denudation, going on both while and after slow disturbance and elevation were taking place, that peaks, rough ridges, ice-worn surfaces, and all the cliffs and valleys of the Highlands in their present form, have been called into existence. They are undergoing further modification now.

Let anyone who wishes to get a clear idea of what is meant by a considerable amount of denudation, ascend Suilven in the west of Sutherland, to which reference has already been made. The mountain is based on a wide, low, undulating plateau of Lewisian gneiss, dotted with unnumbered lakes and tarns. From this plateau it rises abruptly into the air, like a little Matterhorn, 2,399 feet in height, and its sides are as steep as those of the noble Swiss mountain. They are formed of horizontal purple Torridon conglomerate and grits, cut by nature into great terraced steps, on which by devious courses the climber reaches the summit. From the top let him turn to the east, and there, five miles distant, set on the same plain, he will descry the steep-sided Canisp, formed of the same strata once united to those of Suilven and Coulmore. Here is 'a monstrous cantle' cut out of these strata, and yet if the reader would multiply the whole height by ten, he would probably not exaggerate the amount of denudation that these ancient rocks have suffered in the Highlands (Fig. 108, p. 317).

Farther south the different nature, both of the Silurian and newer rocks, coupled with other geological accidents, has produced the great valleys of the Forth and Clyde, and the tamer but still hilly scenery of the Southern Uplands. These heights of the south of Scotland do not form a range. They consist in reality chiefly of a table-land, or old *plain of denudation* with occasional mountain peaks, older for the most part than the Upper Old Red Sandstone and Carboniferous rocks; which plain, after being long buried, was subsequently again exposed by denudation of the overlying strata.

The present scenery of hill and valley in the southern part of Scotland is therefore, in great part, the result of the waste of this old tableland, and the scooping out of valleys and lake-basins, by rain, rivers, and ice, which, as a great ice-sheet, at one time covered the whole of Scotland and much more besides. The great ice-sheet eventually shrank into minor glaciers, which occupied the valleys among the higher hills and left moraines there, during those oscillations of temperature that marked what we call the Glacial epoch. A continual modification of the scenery is still in progress from the effects of air, rain, frost, rivers, and the sea.[1]

[1] For further illustrations of this subject see *The Scenery of Scotland viewed in connection with its Physical Geology*, by A. Geikie, ed. 2, 1887.

CHAPTER XXX.

THE GEOLOGY AND SCENERY OF ENGLAND AND WALES:—THE MOUNTAINS OF WALES AND THE WEST OF ENGLAND—THE VALLEY OF THE SEVERN, AND THE OOLITIC AND CHALK ESCARPMENTS—THE HILLY CARBONIFEROUS GROUND OF THE NORTH OF ENGLAND, ITS BORDERING PLAINS AND VALLEYS; AND THEIR RELATION TO THE MOUNTAINS OF WALES AND CUMBERLAND.

THE general physical structure of England and Wales, from the coast of North Wales to the Chiltern Hills, will be easily understood by a reference to Fig. 109, and to the following descriptions; and this structure is eminently typical, explaining, as it does, the physical geology of the greater part of England south of the Staffordshire and Derbyshire hills.

The Lower Silurian rocks of Wales (No. 1) consist chiefly of slaty and solid gritty strata, accompanied by, and interbedded with, numerous felspathic lavas and beds of volcanic ashes; and mingled with these there are numerous bosses and dykes of felstone, quartz-porphyry, greenstone, and the like. These last, by their superior hardness, give a truly mountainous character to nearly the whole of North Wales, from Merionethshire and Montgomeryshire to the Menai Straits. In part of north Pembrokeshire also, in a less degree, igneous rocks are largely intermingled with the Cambrian and Lower Silurian strata, and these, by help of denudation, now form a very hilly country.

Without again entering into details, it is here sufficient to state that the Cambrian and Lower Silurian epoch was ended in the British area by disturbance and contortion of the strata, and their upheaval into land. This disturbance necessarily gave rise to long-continued denudations of this early territory, both by ordinary atmospheric agencies, and also by the action of the waves of the sea of a younger Silurian period, the evidence of which is seen in the conglomerates of the Llandovery beds, which, mingled with marine shells, lie unconformably on the denuded edges of the older strata of the Longmynd in Shropshire, like a consolidated sea-beach (see Fig. 27). Slow submergence then took place beneath the sea, in which the Upper Silurian rocks were gradually accumulated unconformably till, perhaps, they entirely buried the Lower Silurian strata (2, Fig. 109), for in places they attained a thickness of from three to six thousand feet.

The uppermost Upper Silurian beds of Wales pass insensibly into the Old Red Sandstone (3, Fig. 109), formed, if we include the entire formation, of beds of red marl, sandstone, and conglomerate, which again pass upwards into the Carboniferous Limestone, which is overlaid there, as in Derbyshire and

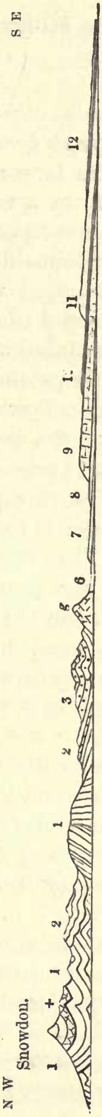


FIG. 109.—DIAGRAM-SECTION FROM THE MENAI STRAITS ACROSS WALES, THE MALVERN HILLS, AND THE ESCARPMENTS OF THE OOLITIC ROCKS AND THE CHALK.

Nos. 1 to 3 represent the disturbed Cambrian, Lower and Upper Silurian, and Old Red Sandstone mountainous country of North Wales, the adjacent counties on the east, and the Malvern Hills *g*. + Eruptive rocks.
6 to 8 the plains and slightly undulating grounds of the New Red Sandstone, Red Marl, and Lias.
9 and 10 the great Oolitic escarpment of the Cotteswold Hills, forming the first tableland.
11 the great escarpment of the Chalk, forming a second tableland, above which lie the Eocene strata, 12.
The Upper Oolites, close below the Chalk escarpment 11, are in places of less height relatively to the sea than the edge of the Oolitic escarpment at 9.

Lancashire, by the Millstone Grit and Coal-measures (see Fig. 115).

Next in the series come the Permian rocks, which, however, rarely occupy so great a space in England as materially to affect the larger features of the scenery of the country. They form a narrow and marked strip on the east of the Coal-measures from Tynemouth in Northumberland to Nottinghamshire, where they chiefly consist of a long, low, flat-topped terrace of Magnesian Limestone (see Map), the scarped edge of which faces west, and overlooks the lower undulations of the Coal-measure area.

There are other patches of Permian sandstones, marls, breccias, and conglomerates, in the south of Scotland, the Vale of Eden, and the west of Cumberland, and they are also here and there present on the borders of the Lancashire, North Wales, Shropshire, and all the Midland coalfields, and they overlie the older rocks of the Abberley and Malvern Hills. They form the striking red cliffs at Teignmouth, Dawlish, and Exmouth in South Devon.

Resting partly on the Permian rocks, partly on older subjacent strata, come the New Red Sandstone and Marl (Bunter and Keuper) of our region. These formations fill the Vale of Clwyd in North Wales, and in the centre of England range from the mouth of the Mersey round the borders of Wales to the estuary of the Severn, eastwards into Warwickshire, and thence northwards into Yorkshire, along the eastern border of the Magnesian limestone (see Map). In the centre of England the unequal hardness of its subdivisions sometimes gives rise to minor escarpments (Nos. 4 and 6, Fig. 42, p. 126), most of them looking west over plains and undulating ground formed of soft red sandstone. Such escarpments are especially remarkable in the case of the Keuper sandstones, which lie at the base of the New Red Marl. These strata having better resisted denudation than the softer red sandstones below, they stand out as bold cliffy scarps facing west, with long gentle slopes to the east. Such are Helsby Hill, that looks out upon the Mersey, near Frodsham; the beautiful terraced scarps of Delamere Forest, the grand castle-crowned cliff of Beeston, near Tarporley, and the beautiful heights, often well wooded, that stretch thence to the south, and form the Peckforton Hills.

In the far south the cliffs of Budleigh Salterton and Sidmouth are formed of pebble-beds and red sandstones of this series, while the overlying red marls appear at Branscombe and Axmouth, and again on the coast of West Somerset near Watchet.

Above the New Red Marl, the Rhætic Beds here and there form gentle escarpments, as in the Polden Hills, near Glastonbury, in Somerset.

The Lias series, Nos. 3, 4, 5, Fig. 7, consists of three belts of strata, running from Lyme Regis on the south-west, through the whole of England, to Yorkshire on the north-east: the Lower Lias limestone and clay, the Middle Lias or Marlstone strata, and the Upper Lias clay. The unequal hardness of the clays and limestones of the Liassic strata causes some of its members to stand out in distinct minor escarpments, often facing west and north-west. The Marlstone No. 4 forms the most prominent of these, as at Edge Hill, and overlooks the broad meadow-land of Lower Lias clay that occupies the centre of England, including the hunting country of the Vale of Belvoir, Melton Mowbray, and Market Harborough. Occasional outliers of Lias, as between Adderley and Whitchurch in Cheshire and Shropshire, and again near Carlisle, bear witness to the former extent of the strata, and to the great denudation they have suffered.

Conformable to and resting upon the Lias are the various members of the Oolitic series (6 to 12, Fig. 7).[1] That portion termed the Inferior Oolite occupies the base, being succeeded by the Great or Bath Oolite, Forest Marble, Cornbrash, Oxford Clay, Corallian Beds, Kimeridge Clay,

[1] See also the 'Table of Formations,' p. 47.

and Portland Beds. These, from their approximate conformity one to the other, occupy belts of variable breadth, extending from Dorset northwards, through Somerset, Wilts, Gloucestershire, Oxfordshire, Northamptonshire, and Leicestershire, to the north of Yorkshire, where they disappear beneath the German Ocean.

In the south of England the Forest Marble forms perhaps the most prominent of the Oolitic escarpments, as noticeable near Sherborne in Dorset. Further north near Bath the Great Oolite is more prominent, extending onwards to Minchinhampton. Then the Inferior Oolite of the Cotteswolds, so well shown in the hills at Stinchcombe, at

FIG. 110.—GENERAL SECTION ACROSS THE ISLE OF PURBECK.

2. Purbeck Limestones and Marls.
1. Portland Oolite.
4. Cretaceous strata.
3. Wealden Sands and Clays.

Cleeve Cloud and Broadway, is the more marked escarpment; while at Edge Hill the Marlstone forms the chief feature. Still further north the Inferior Oolite makes the great escarpment known as the Lincolnshire Cliff. In Yorkshire the Hambleton and Howardian Hills are formed of Corallian Beds, and other moorlands in the eastern part of the county of various portions of the Lower Oolites and Lias, as in the Cleveland Hills.

The fluvio-marine Purbeck Beds and the fresh-water Wealden Beds succeed the Portland formation in the southern parts of England; and they are overlain by the Lower Greensand, Gault, Upper Greensand, and Chalk, in apparent conformity when we cross the Isle of Purbeck from south to north (see Fig. 110). The unconformity is shown when (as in Fig. 111) we pass westwards into Devonshire. These various divisions tend to diversify the scenery over large areas, from the Blackdown Hills of Devonshire, across the Dorsetshire, Wiltshire, and Hampshire Downs to the Wealden area, and northwards through east Lincolnshire to the wolds of Yorkshire.

In order fully to understand their influence on the scenery, it is needful to consider briefly the relations between the Cretaceous and Oolitic formations. During the period that the Oolitic strata formed part of the land through which the river flowed that deposited the Wealden and Purbeck Beds, they were undergoing constant waste, so that in the course of time, having been previously tilted upwards to the west with an eastern dip (Fig. 111), they were worn into what I have elsewhere termed *a plain of marine denudation* (see p. 347). The submergence of the Wealden area was followed by the progressive sinking of the Oolitic and older strata further west, so that, as the successive members of the Cretaceous formations were deposited, it happened that by slow sinking of the land, the Lower Greensand crossed the denuded outcrops of various Oolitic strata, so as to rest on the Kimeridge Clay and Corallian rocks in parts of Wiltshire and Berkshire. Again, the Upper Cretaceous strata gradually overstepped the edges of the Lower Greensand, but crossed the outcropping Oolitic and Liassic formations, till at length they rested on the New Red series,

FIG. 111.—OVERLAP OF THE JURASSIC AND NEW RED STRATA BY THE UPPER CRETACEOUS FORMATIONS.

1. Represents Palæozoic strata. 2. New Red Beds. 3. Lias. 4, 5, 6. Various members of the Oolites, and 7. The Upper Cretaceous strata. The dotted line represents the original continuation of the Upper Cretaceous strata westward, the slope marked × the present escarpment of the Chalk, and the hills marked with asterisks (*) outlying patches of the Chalk and Upper Greensand, the relics left by old denudations, and which help to prove the original far westward extension of the Upper Cretaceous strata.

FIG. 112.—POTHOLES IN THE CHALK OF SAVERNAKE FOREST, NEAR MARLBOROUGH.

and even on the Palæozoic strata of Devonshire itself, as shown in Fig. 111.

The upheaval of the Chalk into land brought this epoch to an end, and those conditions that contributed to its formation ceased in our area.

This brings us to the last divisions of the British strata which I shall now name. These were deposited on the Chalk, and are termed Eocene formations. Their pebble-beds are composed almost entirely of rolled flint, indicating that Chalk cliffs bounded the sea-shores. Moreover, their extension much further west is indicated by the occurrence of outlying fragments, sometimes preserved in 'pipes' or 'potholes,' as represented in Fig. 112, where

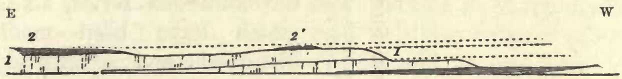


FIG. 113.—SECTION OF THE CHALK ESCARPMENT WITH OUTLIER OF EOCENE BEDS.

1. Chalk. 2. Main mass of Eocene Beds. 2'. Outlier of Eocene Beds.

relics of the Woolwich and Reading Beds have been preserved. These have been let down into the potholes, by the dissolving of the underlying Chalk by the carbonic acid in rain-water, and thus pockets of Eocene strata have been preserved. The proof of this original extension westward is shown in the diagram (Fig. 113).

The Eocene beds being formed of soft strata—chiefly clays and sands—though they make undulating ground, form no bold scenery. The same may be said of the Pliocene strata.

Having given this brief account of the stratigraphical features of the principal formations, it is desirable to indicate more particularly the part that some of them play in producing the scenery of the country.

In the far west, in Devon and Cornwall and in Wales, also in the north-west, in Cumberland, and in the Pennine chain which stretches through Derbyshire and parts of Yorkshire, Durham, and Northumberland, to join the high lands of the Scottish border, we have what forms the mountainous and more hilly districts of England and Wales. Nearly the whole of this area is formed of Palæozoic strata, of Cambrian and Silurian rocks with their igneous interstratifications, of Devonian rocks and Old Red Sandstone, and of the Carboniferous series, all of which have been much disturbed and extensively denuded.

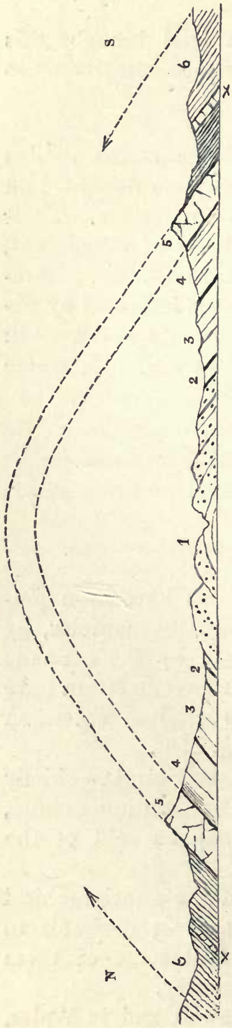


FIG. 114.—SECTION ACROSS THE CAMBRIAN AND LOWER SILURIAN ROCKS OF MERIONETHSHIRE.

1. Harlech Grits. 2. Menevian Beds. 3. Lingula Flags. 4. Tremadoc and Arenig Slates. 5. Igneous series. 6. Llandeilo and Bala Beds. × Bala Limestone.

The Lower Cambrian rocks of Merionethshire, for example, marked 2 on the map, were once buried deep beneath more than 20,000 feet of Lower Silurian strata. Let anyone climb to the rugged centre of this Cambrian area, and he will find that on three sides, the great anticlinal boss of Cambrian grits is set in a curved frame of higher Cambrian and Lower Silurian slates and volcanic beds, and on the fourth it is bordered by the sea. All these rocks, and many more besides, once overlay the Lower Cambrian Beds, in the form of a great anticlinal curve, and have since been removed by denudation; and thus it happens that between the estuary of the Mawddach below Dolgelly, and that of Traethbach at Portmadoc, we find this inner group of gritty hills more than half enclosed by that somewhat distant ring of higher mountains, Cader Idris, the Arenigs, Manods, and Moelwyns, which are higher, as a rule, simply because of the hard quality of the great inclined beds of igneous rock, of which they are so largely composed (Fig. 114).

It is, therefore, easy to understand how it happens that with disturbed and contorted beds of such various kinds, those great denudations, which commenced as early as the close of the Lower Silurian period, and have been continued intermittently ever since, through periods of time so immense that the mind refuses to grapple with them—it is, I repeat, easily seen how the outlines of the country have assumed such varied and rugged forms as those which North Wales, and in a less degree parts of North Pembrokeshire, Devon, and Cornwall, now present.

The Secondary and Tertiary strata have not been anywhere disturbed nearly to the same extent as the Palæozoic formations in England. Though occasionally traversed by faults, yet with rare exceptions most of the strata have been elevated above the water without much bending or contortion on a large scale. What chiefly took place was a slight uptilting of the strata on the west, which, therefore, all through the centre of England, dip as a whole slightly but steadily to the east and south-east. This is evident from the circumstance that on the Cotteswold Hills the lowest Oolitic formation (Inferior Oolite, No. 9, Fig. 109) forms the western edge of the tableland, while, in spite of a few minor escarpments that rise above the surface of this upper plain, the uppermost Oolitic beds that dip below the Cretaceous strata, are often at a lower level than the Inferior Oolite at the edge of the plateau.

The great result, then, of the disturbance and denudation of the Palæozoic strata, and of the lesser disturbance and denudation of the Secondary rocks, is, that the physical features of England and Wales present masses of Palæozoic rocks, forming groups of mountains in the west, then certain plains and undulating grounds composed of New Red Sandstone, Marl, and Lias, and then two great escarpments, the edges of tablelands, which rise in some places to a height of more than a thousand feet: the western one being formed of Oolitic, and the eastern of Cretaceous strata, which, in their turn, are overlain by the Eocene series of the London and Hampshire basins (see Fig. 109).

Through the centre of the northern part of England a great tract of Palæozoic country, more than 200 miles in length, stretches from the southern part of Derbyshire to the borders of Scotland, and joins with the hilly ground of Berwickshire. It consists mainly of Carboniferous rocks. Further west, between Morecambe Bay and the Solway, lie the older rocks of the Cumbrian area, separated from the Carboniferous formations of Northumberland, Durham, and Yorkshire, by the Permian beds of the Vale of Eden.

As far as the northern borders of the Lancashire and Yorkshire coal-fields, the Carboniferous rocks lie in the form of a broad *anticlinal curve.* At the southern end of this area, a wide tract of Carboniferous Limestone hills, ranging up to 1,200 feet in height, occupies the centre of the anticlinal curve, on each side of which the Yoredale Shales and thick strata of Millstone Grit dip east and west as the case may be. The latter, being interstratified with comparatively soft beds of shale, run in long bold escarpments (Fig. 115), that often trend north and south both on the west and east sides of the Carboniferous Limestone; fine examples of these may be seen in the country near Chatsworth on the east, and between Chapel-en-le-Frith, Buxton, and Hartington, and the neighbourhood of Leek, on the west. The Millstone Grit escarpments are generally separated from the limestone hills by a deep valley excavated in the soft Yoredale Shales. Narrow dry dales are common in the Carboniferous Limestone region, and probably some of these are the relics of old underground watercourses, the roofs of which have fallen in. Elsewhere rivers traverse the dales, some of them, like the classic Dove, having cut their way through gorges of tall limestone cliffs.

In the northern part of Derbyshire, near Hathersage and the High Peak, the Millstone Grit lies in broad plateaux, often from 1,000 to 1,200 feet in height.

If from the Snake Inn on the Glossop road you climb the High Peak, or, as it is often called, Kinder Scout, taking Fairbrook as your route, you first pass across shales with beds of Yoredale Grit, over which the water falls in tiny cascades, and at length, high on the top, the view is barred by a great cliff of rock running in a sinuous line to right and left. It consists of coarse quartzose sandstone, covered in great part by peat, which in all directions is intersected by devious steep-sided water-worn channels. If you could look down upon it, it would appear somewhat as in Fig. 116, its whole length being about five miles by two in breadth. Kinder Scout is in the centre of a long, low, anticlinal curve, and the strata lie nearly flat, while to the right and left the equivalent strata form definite scarps, dipping in opposite directions.

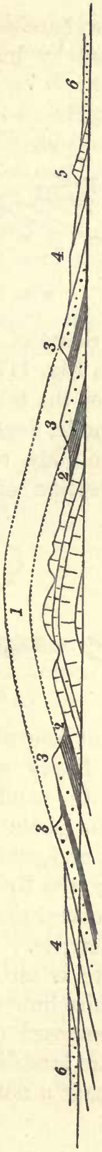


FIG. 115.—SECTION ACROSS THE CARBONIFEROUS ROCKS OF DERBYSHIRE AND LANCASHIRE.

1. Carboniferous Limestone forming the hilly centre of the anticlinal curve. 2. Yoredale Shales, soft, and forming valleys of denudation. 3. Terraced escarpments of hard sandstones, Millstone Grit. 4. Coal-measures, consisting of softer rocks, generally forming a lower undulating country. 5. Escarpment of Magnesian Limestone (Permian) overlaid by 6, New Red Sandstone.

Where bare of peat, the surface of this little tableland is marked by numerous monumental-looking pillars of

FIG. 116.—KINDER SCOUT, HIGH PEAK.

stone. Some of these have such forms as in the following diagram, Fig. 117, and I give them to show that even on the top of the tableland, where of running water there is almost none, degradation and lowering of the surface does not absolutely cease. This work is aided by the easy decomposition of the detrital felspar, which forms an

FIG. 117.—WEATHERED ROCKS.

important ingredient in this coarse-grained sandstone. During heavy gales that sweep across the high bare plateau, the sand is driven along the surface, and grating along the bases of the projecting masses of rock, these become undercut, and eventually must topple over. In this way, the Brimham rocks, various rocking-stones, and other isolated rock-masses or 'tors' have been formed in other districts.

There is no area that shows better than this part of Derbyshire how valleys have been formed in a high tableland composed of Carboniferous sandstones and shales. There are landslips everywhere. Going up the valley from Hathersage a notable landslip is to be seen on the hill-side west of the Derwent and south of Yorkshire Bridge, while on the road to Glossop there are several on either side of the valley. On the north side of the valley of the Ashop, the shattered masses cumber the hill-side for at least three miles, and on the east side there is one vast landslip a mile in length. The whole hill-side has slipped bodily away, part lies in tumbled ruins all the way down to the river, while part still stands in tower-like peaks and solid flat-topped castle-like masses, called Alport towers and Alport castles.

The upper strata of the tableland consist of thick beds of sandstone, much jointed, and easily permeated by rain-

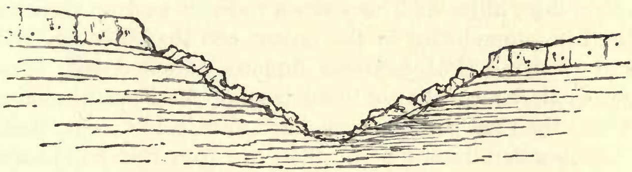


FIG. 118.—LANDSLIPS.

water; the shale beneath becomes softened and slippery, and great masses of sandstone slip over the brow, and, once there, by gravity slowly find their way to the bottom of the valley. There the river attacks and carries away the crumbling ruins, and the valley goes on increasing in size.

It requires little imagination to divine how such valleys began to be formed by streams running in slight inequalities on the very top of the sandstone plateau, till at length, channels being cut through the sandstones, landslips came in aid, and are still in progress.

If we now construct a section from the Menai Straits, across Snowdon and over the Derbyshire hills to the east of England, the arrangement of the strata may be typified in the manner shown in Fig. 119. In the west, rise the older disturbed Cambrian and Lower and Upper Silurian strata, Nos. 1 to 3, which form the mountain region of Wales. On the east of these lies an upper portion of the Palæozoic rocks, 4, consisting of Carboniferous beds with an escarpment facing west. They are less disturbed than the underlying Cambrian and Silurian strata on which they lie unconformably. Then, in Cheshire, to the east of the Dee, lie the great undulating plains of the New Red series, 5, and these form plains because they consist of strata that have never been much disturbed and still lie nearly flat, and are soft and easily denuded, whence, in part, the soft rolling undulations of the scenery. Then more easterly, from under the strata of New Red Sandstone, the disturbed Coal-measures again rise, together with the Millstone Grit and Carboniferous Limestone forming the Derbyshire hills, 6. These strata form an anticlinal curve, the Limestone being in the centre, and the Millstone Grit and overlying Coal-measures dipping west and east. Together they form the southern part of the Pennine chain. Above the Coal-measures we have, first, a low escarpment of Magnesian limestone 7, then the New Red Sandstone and Lias plains 8, which are covered to the east by the Oolite 9, forming a low escarpment, the latter being followed by that of the Chalk 10.

Further north, if a section were drawn across England from the Cumberland mountains south-easterly to Bridlington Bay, the following diagram (Fig. 120) will explain the general arrangement of the strata, and the effect of this on the physical geography of the district.

On the west there are the Green Slates and Porphyries (Borrowdale Series), No. 1, consisting of lavas and volcanic ashes, hard but of unequal hardness, and some of them, therefore, by help of denudation giving specialities of shape to some of the loftiest mountains of Cumberland. They form the rough craggy features of Scafell and Borrowdale, while the Skiddaw Slates yield smoother outlines, like those of Skiddaw. Then comes 2, the Coniston Limestone, overlain by Upper Silurian rocks, 3, forming a hilly country, between which and the Carboniferous Grits, 5, lies the

FIG. 119.—SECTION FROM SNOWDON TO THE EAST OF ENGLAND.

5. New Red Strata.
4. Carboniferous Rocks.
1 to 3. Cambrian and Silurian Rocks.

8. New Red Strata and Lias.
7. Magnesian Limestone.
6. Derbyshire Hills (Carboniferous).

10. Cretaceous Strata.
9. Oolites.

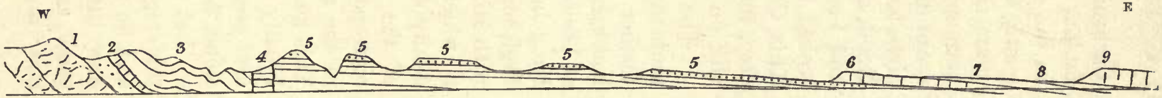


FIG. 120.—SECTION FROM CUMBERLAND TOWARDS BRIDLINGTON.

3. Upper Silurian Grit, &c.
2. Coniston Limestone.
1. Igneous rocks or Green Slates and Porphyries (Borrowdale Series) of Lower Silurian age.

6. Magnesian Limestone.
5. Yoredale Rocks and Millstone Grit.
4. Carboniferous Limestone, between faults.

9. Chalk.
8. Jurassic Rocks.
7. New Red Strata.

FIG. 121.—SECTION FROM INGLEBOROUGH TO THE EAST YORKSHIRE MOORS.

1. Carboniferous Limestone. 2. {Millstone Grit. / Yoredale Rocks. 3. Magnesian Limestone. *v.* Vale of York. 4. {Lias. / New Red Rocks. 5. Oolites.

Carboniferous Limestone bounded by faults. Then comes a marked feature in the district consisting of the long, gently sloping Yoredale rocks and Millstone Grit, No. 5, which are denuded here and there into outliers. These rocks dip easterly till they pass out of sight beneath the Magnesian Limestone, No. 6, and the plains of New Red Beds and Lias, 7 and 8, and these are overlooked by an escarpment of Chalk, 9. This Chalk is surmounted by Boulder-clay, the eastern edge of which forms a cliff on the sea-margin.

The diagram (Fig. 121) again represents the general structure of the region further north, on a line from Ingleborough on the west to the Oolitic moors of Yorkshire. On the west lie the outlying heights of the ancient camp of Ingleborough, and of Penyghent, capped with Millstone Grit and Yoredale rocks, 2, which, intersected by valleys, gradually dip eastward, the average slope of the ground over long areas often corresponding with the dip of the strata in the manner shown in the diagram. This kind of slope is called a *dip-slope*. Finally the strata disappear under the low escarpment of Magnesian Limestone, 3.

Let the reader attentively consider this diagram (Fig. 121 and also Fig. 120), and he may, I hope, convince himself how little ordinary valleys, large or small, are directly produced by fractures and 'convulsions of Nature,' for in this and many similar cases, what can be their origin but the long-continued erosive powers of rain and running water? East of the Magnesian Limestone lies the plain, *p*, almost as flat as a table, and covered to a great extent with an oozy loam, like the warps of the Wash and the Humber, and like these, perhaps, formed of old marine and river sediments. The New Red and Lower Lias strata, 4, lie beneath the warp, and for the most part below the level of the sea; and high on the east, like a great rampart, the escarpment of the Oolites, 5, rises in places to a height of more than 1,100 feet, with all its broad-topped Tabular hills and moorlands, and deep well-wooded valleys. Such is the anatomy of the fertile Vale of York and its neighbourhood.

CHAPTER XXXI.

THE ORIGIN OF RIVER-VALLEYS — THEIR RELATION TO TABLELANDS—ESCARPMENTS CUT ACROSS BY RIVERS —GEOLOGICAL DATES OF DIFFERENT RIVER-VALLEYS —THE SEVERN, THE AVON, THE THAMES, THE FROME, AND THE SOLENT—TRIBUTARIES OF THE WASH AND THE HUMBER—THE EDEN AND THE WESTERN-FLOWING RIVERS—SCOTLAND.

It is difficult even approximately to settle what are the geological dates of the valleys through which many rivers run; or, in other words, when they first began to be scooped out, and through what various periods their excavation was intermittently or continuously carried on. In Wales, for example, there are vast numbers of rivers and brooks, small and large, and when we examine the relation of these streams to the present surface of the country, we often find it very remarkable. Fig. 122 is a diagram representing no particular section, but simply the general form of the country across the Lower Silurian strata of Cardiganshire, as shown by myself in 1847.[1] The dark-coloured part represents the form of the country given in the original sections on a scale of six inches to a mile horizontally and vertically. The strata of this area, and, indeed, of much of South Wales, are exceedingly contorted. The level of the sea is represented by the lower line; and if we take a straight-edge, and place it on the topmost part

[1] See Ramsay, *Rep. Brit. Assoc.* for 1847, Sections, p. 66; and 'On the Denudation of South Wales and the adjacent Counties of England,' *Mem. Geol. Survey*, vol. i. p. 297.

of the highest hill, and incline it gently seaward, it touches the top of each hill in succession, in the manner shown by the line *b b*. This line is as near as can be straight, and, on the average, has an inclination of from one to one and a half degrees; and it is a curious circumstance that in the original line of sections there were no peaks rising above that line—they barely touched it and no more. It occurred to me, when I first observed this circumstance, that at a period of geological history of unknown date, perhaps older than the beginning of the deposition of the Permian and New Red strata, this inclined line that touches the hill-tops must have represented a great *plain of marine denudation* (Fig. 122).

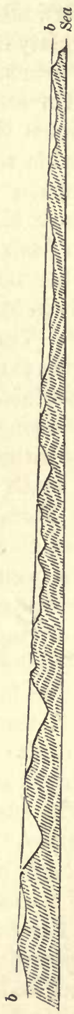


FIG. 122.—PLAIN OF MARINE DENUDATION.

Atmospheric degradation, aided by sea-waves on the cliffs by the shore, is the only power that can denude a country so as to shave it across, and make a plane surface either horizontal or slightly inclined. If a country be sinking very gradually, and the rate of waste by all causes be proportionate to the rate of sinking, this will greatly assist in the production of the phenomena we are now considering: and a little reflection will show, that the result would be an inclined plane like that of the straight line *b b* in the diagram. Let South Wales be such a country: then when that country was again raised out of the water, the streams made by its drainage immediately began to scoop out valleys; and though some inequalities of contour forming bays may have been begun by marine denudation during emergence, yet in the main the inequalities below the line *b b* have been made by the influence of rain and running water. Hence the number of deep valleys, many of them steep-sided, that diversify Wales, all the way from the Towey in Caermarthenshire to the slaty hills near the southern flanks of Cader Idris and the Arans.

On ascending to the upper heights, indeed, anywhere between the Vale of Towey and Cardigan Bay, it is impossible not to be struck with the average uniformity of elevation of the flat-topped hills that form a principal feature of the district. The country already described as seen from Ramsey Island is part of this plain, and much further north let anyone ascend Aran Mowddy or Cader Idris in Merionethshire, and look to the south and south-east. Thence he will behold, as far as the eye can reach, a wide extent of flat-topped hills, which form the relics of a vast tableland, now intersected by numerous rivers, which, in the long lapse of untold ages, have scooped out unnumbered labyrinthine valleys eastward into Montgomeryshire, and far south into Cardiganshire. Between the rivers Towey and Teifi, and in other areas, these hills, in fact, form the relics of a great plain or tableland in which the valleys have been scooped out; and in the case of the country represented in Fig. 122, the higher land, as it now exists, is only the relic of an average general gentle slope, represented by the straight line, *b b*, drawn from the inland heights towards the sea.

Nothing is more remarkable in the history of rivers than the circumstance that very frequently they run straight athwart bold escarpments, which, at first sight we might suppose, ought to have barred the course of the streams. The Wye in South Wales, for example, runs through a bold escarpment of Old Red Sandstone hills; and the same is the case with the Usk.

For long it was customary to attribute such breaches in escarpments, and indeed valleys in general, to disturbances and fractures of the strata, producing a wide separation, and actually making hills. But when we realise that thousands of feet of strata have often been removed by denudation since the great disturbances of the Welsh strata took place, it becomes clear that the present valleys are in no way immediately connected with them; for even if there be dislocations or faults in some of the valleys, these faults when formed were, as far as regards the present surface, thousands of feet deep in the earth. All they

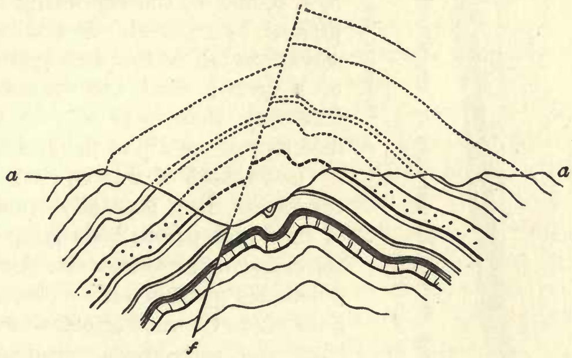


FIG. 123.—FAULTED ANTICLINAL STRUCTURE.

a Present surface of the ground.
The dotted lines show the continuation of an anticlinal curve broken by a fault *f*; and they show that above the surface *a a* the strata have been removed by denudation.

could do might have been to establish lines of weakness along which subsequent denudation may have excavated valleys (see Fig. 123).

The real explanation of such cases as those of the Wye and the Usk is this. At some period, now uncertain, the beds of the Old Red Sandstone, well seen in the escarpment of the Brecknock Beacons, *a*, and the Caermarthen Fans, once spread much farther westward, forming a great plain, *b b* (Fig. 124), the result of earlier denudations. This plain sloped gently eastward, and the dotted line shows the general state of old outcrops of the strata. The river then ran over ground perhaps even higher than the tops of the hills of the present escarpment, and by degrees it cut itself a channel approximately in its present

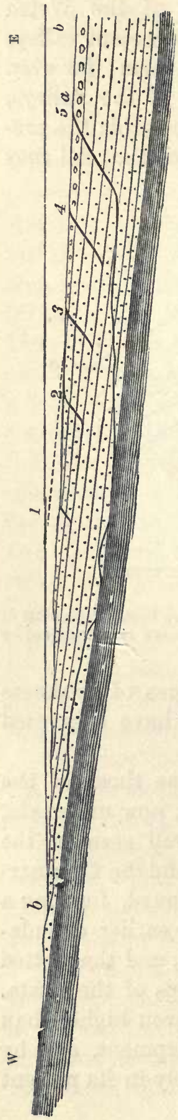


Fig. 124.—Diagram showing the Mode of Formation of the Escarpment of the Brecknock Beacons and Caermarthen Fans.

b b. Original plain sloping gently eastward. 1, 2, 3, 4, 5. Successive escarpments.

course, but varied and widened by subsequent river action; and, as it cut out that valley, the escarpment, by the influence of rain and other atmospheric causes, gradually receded to the points marked 1, 2, 3, 4, 5, and *a*, the last being the present escarpment. For all observations tell us that escarpments of a certain kind are wasted in this way, that is to say, in the direction of the dip of the strata.

One reason of this is, that escarpments very generally consist of hard and porous beds lying on softer and impervious strata. Along a denuded plain of such rocks, the river starts its winding course over hard and soft strata, gradually deepening its channel. The softer strata being more easily worn away along the line of strike, lateral valleys and escarpments begin to be formed. Once established, the weather acting on the joints and other fissures in the rocks, takes more effect on the steep slope of the scarp than on the gentle slope that is inclined away from the scarp. The loosened detritus on the steeper slope slips readily downward, and is easily removed by floods of rain; and thus the escarpment constantly recedes in a given direction, while on the opposite gentle slope the loosened detritus, smaller in amount, travels so slowly that it rather tends to block the way against further waste. In this way we can explain how the Wye and the Usk break through the Old Red Sandstone and find their way to the estuary of the Severn; why the Severn itself breaks through the Upper Silurian escarpment of Wenlock Edge; why certain other rivers—such as the Dee in Wales, and the Derwent in Cumberland—cut through escarpments of Carboniferous Limestone; and how, indeed, the same kinds of phenomena are everywhere prevalent under similar circumstances.

When we consider the origin of some of the larger river-valleys, there is a great deal that is difficult to account for. One thing is certain, that before the Glacial epoch the greater contours of the country were much the same as they are now. The mountains of Scotland, Wales, and Cumberland, and the great Pennine chain, existed then, somewhat different in outline, and yet the same essentially; the central plains of England were plains then, and the escarpments of the Chalk and Oolites existed before the Glacial period. All that the ice did was to modify the surface by degradation, to smooth its asperities by rounding and polishing them, to deepen valleys where glaciers flowed, and to scatter quantities of moraine-detritus, partly in the shape of boulder-clay, and sands and gravels, over the plains that form the eastern and central part of England.

If we examine the valley of the Severn from Bristol northwards through Coalbrookdale, we find that for a large part of its course the river runs down a broad valley, between the old Palæozoic hills and the escarpment formed by the tableland of the Cotteswold Hills which are highest in the neighbourhood of Cheltenham. That valley certainly existed before the Glacial epoch, because we find boulders and boulder-drift far down towards Tewkesbury; and therefore we may conclude that before the Glacial epoch this part of the Severn ran very much in the same course as it does at present. After that period, the

Severn, following in the main its old course, cut a channel for itself through the boulder-drift that partially blocked up the original valley in which it ran. *When* that original valley was formed through which the older Severn ran is the point to discover.[1]

About the close of their epoch the Oolitic formations were over large areas raised above the sea, and remained a long time out of water; and, during that period, those atmospheric influences that produced the sediment of the great Purbeck and Wealden delta were slowly wearing away and lowering the land, and reducing it to the state of a broad undulating plain. At that time the Oolitic strata still abutted on the mountain country now forming Wales and parts of the adjacent counties. They covered the Mendip Hills, and passed westward as far as the mountains of Devon, and between Wales and Devonshire through what is now the Bristol Channel. The whole of the middle of England was likewise covered by the same deposits, overlying the rocks that now form the plains of Shropshire, Cheshire, Lancashire, and the adjoining areas, so that the Lias and Oolites passed out to the area now occupied by the Irish Sea, and perhaps far beyond. In brief, most of the present mountainous and hilly lands of the mainland of Britain were mountainous and hilly then, and must have been much higher than now, considering how much they have since suffered by denudation. The general arrangement of the strata would then be somewhat as in Fig. 125.

The submersion of this low-lying area brought the deposition of the Wealden strata to a close, and the Cretaceous formations were deposited above the Wealden and Oolitic strata, so that a great unconformable overlap by the Cretaceous strata took place across the successive outcrops of the Wealden, Oolitic, and older Secondary formations (see Fig. 126).

A similar overlapping of the Oolitic by the Cretaceous

[1] Ramsay, 'On the River-courses of England and Wales,' *Quart. Journ. Geol. Soc.*, vol. xxviii. p. 148.

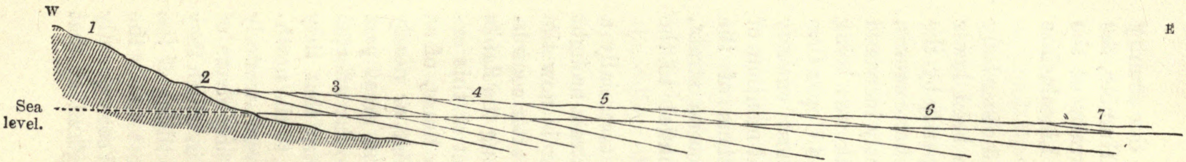


Fig. 125.—General Arrangement of the Lower Secondary Formations before the Deposition of the Upper Secondary Strata.

1. Disturbed and hilly Silurian, Old Red, and Carboniferous strata. 2. New Red Beds. 3. Lower Lias. 4. Middle and Upper Lias. 5. Lower Oolites. 6. Middle Oolites. 7. Upper Oolites and Purbeck Beds.

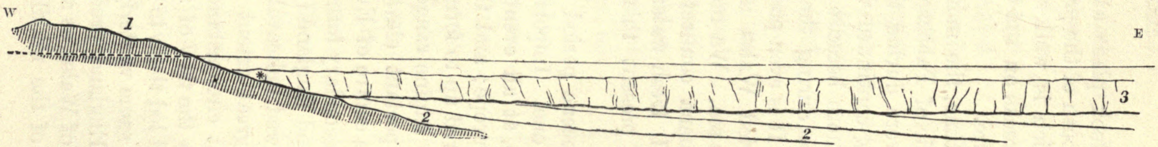


Fig. 126.—Overlap of the Lower Secondary Formations by the Cretaceous Strata.

1. Disturbed hilly land, as in Fig. 111. 2. New Red, Liassic, and Oolitic strata, &c. 3. Cretaceous strata lying *unconformably* on and overlapping the denuded edges of No. 2, and abutting on the half-submerged mountains of Wales at *.

formations took place at the same time in the country north and south of the present estuary of the Humber, the proof of which is well seen in the unconformity of the Cretaceous rocks on the Oolites and Lias of Lincolnshire and Yorkshire.

At this time, the mountains of Wales, and other hilly regions made of Palæozoic rocks, must have been lower than they were during the Oolitic epochs; partly by the effect of long-continued waste due to atmospheric causes, but much more because of gradual and greatly increased submergence during the time that the Chalk was being deposited. It is even possible that during the Upper Cretaceous period Wales may have sunk almost entirely beneath the sea. We may omit any detailed mention of the phenomena connected with the depositions of the marine and fresh-water Eocene and Oligocene strata, because at present this subject is not essential to the argument.

The Miocene period of old Europe was essentially a continental one. Important disturbances of strata brought it to a close, at all events physically, in what is now the centre of Europe; and the formations were, after consolidation, heaved up to form new mountains along the flanks of the older Alpine range. One marked effect of this extremely important elevation, after Miocene times, of so much of the centre of Europe was, that the flat, or nearly flat-lying Secondary formations that now form great part of France and England (then united), were so far affected by the renewed upheaval of the Alps and Jura that they were to a great extent tilted, at low angles, to the north-west. That circumstance gave the initial north-westerly direction to the flow of so many of the existing rivers of France, and led them to excavate the valleys in which they run. This same westerly and north-westerly tilting of the Chalk of England produced a gentle slope towards the mountains of Wales, as shown in Fig. 127, and consequently the rivers of the middle and south of England at that time flowed westerly. This first induced the lower portion of the Severn to take a southern course between the hilly land of Wales and Herefordshire and the long slope of Chalk then rising to the east. Aided by the tributary streams of Herefordshire, it began to cut a valley towards what afterwards became the Bristol Channel, and established the beginning of the escarpment of the Chalk (*e*, Fig. 127), which has since gradually receded so far to the east, chiefly by atmospheric waste. If this be so, then the origin of the valley of the Severn between *e* and 1 is of immediate post-Miocene date, and is one of the oldest in the lowlands of England. Many of the valleys of Wales must, however, be very much older.

The course of the Warwickshire Avon, which is a tributary of the Severn, and joins it at Tewkesbury, is of later date than the latter river. It now rises at the base of the escarpment of the Oolitic rocks east of Rugby, and gradually established and increased the length of its channel in the low grounds now formed of Lower Lias and New Red Marl, as that escarpment was wasted back.

If the general slope of the surface of the Chalk of this part of England had been easterly instead of westerly at the post-Miocene date alluded to, then had any such river been called into existence, its initial course would also have been easterly, like that of

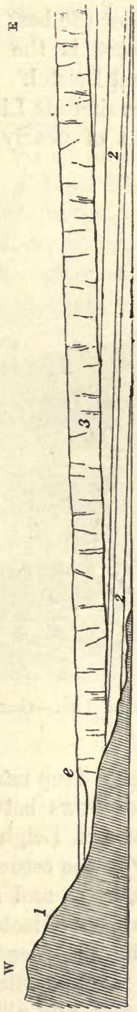


Fig. 127.—Post-Miocene Westerly Dip of the Cretaceous Strata.

1. Old Wales. 2. Oolitic strata, &c. 3. Chalk, &c. The surface of the Chalk slopes gently from east to west.

the Thames and the rivers that flow into the Wash and the Humber.

One of the best known rivers that enters the estuary of the Severn is the Wiltshire Avon, which flows through Bath and Bristol. West of Bristol there is a high plateau of Carboniferous Limestone, the flat top of which attains a height of nearly 400 feet above the level of the sea.

FIG. 128.—GORGE OF THE AVON AT CLIFTON, BRISTOL. Looking down the river.

Through a deep narrow gorge in this limestone (Fig. 128) the river flows between Clifton and Durdham Downs on the east and Leigh Wood on the west, afterwards finding its way to the estuary of the Severn at King's Road. Above Bristol, north and south of the river, the country consists of a number of isolated flat-topped hills, of which Dundry Hill and the Mendips form conspicuous members, while in the neighbourhood of Bath, Lansdown, Charmy Down, Odd Down, and all the minor Oolitic plateaux, now form portions of what was once a continuous broad tableland with minor undulations. In these regions the Avon takes its rise, swollen by many north-flowing tributaries, of which the Chew and Frome rise on the north flank of the Mendip Hills. North of Bath, several streams flow into the Avon through deep and beautiful valleys which have been scooped out of the Oolitic plateau, while others pass through the soft undulating grounds of Lias, New Red Marl, and Coal-measures that lie west of the bold Oolitic escarpment between Bath and Wotton-under-Edge. Some of these streams rise at heights approximately as high as the summit level of the limestone gorge through which the Avon flows below Bristol.[1]

The true explanation is, that in some post-Cretaceous period of geological history, the surface of the country on either side of the river above the present gorge formed a great plain, somewhat higher than the summit level of the Carboniferous Limestone plateau. This plain being slightly inclined to the west at the time the Severn was scooping out its valley, the ancient Avon flowed over the top of the plateau of Clifton and Durdham Downs, through a minor inequality of the surface, and steadily deepened its channel. As it did this, so in like proportion the river and its tributaries in the upper part of their courses gradually wasted and lowered the hill-sides and valleys through which they flowed, being aided by rains and snows and all the ordinary agents of atmospheric denudation; and thus it happens, that what was once a high slightly inclined tableland, has been converted partly into flat-topped fragments of a high plain, and partly into undulating hills and vales; while in the great Oolitic plateau that stretches eastward as far as the Chalk escarpment, we have still remaining a large tract of the ancient plain, with this difference, that the average gentle slope of its surface is now east instead of west.

This naturally leads to the question, Why is it that the Thames, and some other rivers that flow through the

[1] See also Jukes, *Geol. Mag.*, 1867, p. 444.

Oolites and Chalk, run eastward? The answer seems to be, that after the original valley of the Severn was well established by its river, a new disturbance of the whole country took place, by which the Cretaceous and other strata were slightly tilted eastward, not suddenly, but by degrees, and thus a second slope was given to the Chalk and Eocene strata, in a direction opposite to the dip, that originally led to the scooping out of the present valley of the Severn. This dip lay east of the comparatively newly formed escarpment of the Chalk indicated by the dark line in Fig. 127 marked *e*. The present Chalk escarpment, in its beginning, is thus of older date than the Oolitic escarpment (Fig. 109, p. 329).

When this slope of the Chalk and the overlying Eocene strata was established, the water that fell on the long inclined plain east of the escarpment of the Chalk necessarily flowed eastward, and the Thames, in its beginning, flowed from end to end entirely over Chalk and Eocene strata.

The river was probably larger then than now, for in these early times of its history the south of England was joined to France, the Straits of Dover had no existence, and the eastern part of the Thames as a river, not as a mere estuary, ran far across land now destroyed, perhaps directly to join an ancient extension of the north-flowing river which we now call the Rhine. At its upper end, west of its present sources, the Thames was longer by about as much probably as the distance between the well-known escarpment of the Cotteswold Hills and the course of the Severn as it now runs; for the original escarpment of the Chalk must have directly overlooked the early valley of the Severn, which was then much narrower than now. By processes of waste identical with those that formed the escarpment of the Wealden area (Figs. 131–133, pp. 368 &c.), the Chalk escarpment gradually receded eastward, and as it did this the valley of the Severn widened, and the area of the drainage of the Thames was contracted.

By-and-by, the outcropping edges of the Oolitic strata becoming exposed, a second and later escarpment began to be formed, while the valley of the Severn gradually deepened; but the escarpment of the Chalk being more easily wasted than that of the Oolite, its recession eastward was more rapid, and this process having gone on from that day to this, the two escarpments in the region across which the Thames runs are far distant from each other.

All this time the Thames was cutting a valley for itself in the Chalk, and by-and-by, when the escarpment had receded to a certain point, its base became in part lower than the edge of the Oolitic escarpment that then, as now, overlooked the valley of the Severn, only at that time the valley was narrower. While this point was being gradually reached, the Thames by degrees was joined by the growing tributary waters that drained part of the surface of the eastward slope of the Oolitic strata, the westward escarpment of which was still receding; and thus was brought about what at first sight seems the unnatural breaking of the river through the high escarpment of Chalk between Wallingford and Reading.

From the foregoing remarks it will be understood why certain sources of the Thames, the Thames Head near Kemble, and the Seven Springs south of Cheltenham, rise so close to the great escarpment of the Inferior Oolite. But just as in times long gone, the sources of the Thames once rose westward of these present springs on the Cotteswolds, so the sources of the river now are not more stationary than those that preceded. The escarpments, both of Chalk and Oolite, are still slowly changing and receding eastward; and as that of the Oolite recedes, the area of drainage will slowly diminish and the Thames decrease in volume. This is a geological fact, however distant it may appear to persons unaccustomed to deal with geological time.

A change in the story of an old river, even more striking than that of the Thames, has taken place in the history of what was once an important stream further south. Before the formation of the Straits of Dover, the solid land of England, consisting of Oolitic, Cretaceous, and Eocene strata, extended far south into what is now the English Channel. The Isle of Wight still exists as an outlying fragment of that land. At that time the Nine Barrow Chalk Downs, north of Weymouth Bay and Purbeck, were directly joined as a continuous ridge with the Downs that cross the Isle of Wight from the Needles to Culver Cliff. Old Harry and his Wife, off the end of Nine Barrow Downs, and the Needles, off the Isle of Wight, are small outlying relics, left by the denudation of the long range of Purbeck Downs that once joined the Isle of Wight to the so-called Isle of Purbeck, and of the land that lay still farther south of Portland Bill, the Isle of Wight, and Beachy Head.

North of this old land, the Dorset Frome, which rises in the Cretaceous hills east of Beaminster, still runs, and, much diminished, discharges its waters into Poole Harbour. But in older times the Solent formed part of its valley, where, swollen by its affluents, the Stour, the Avon, the Test, and the Itchin, it must have formed a large river, which, by great subsequent denudations and changes in the level of the land, has resulted in the wide channel through which the semi-estuarine waters of the Solent now flow.[1]

The same kind of argument that has been applied to the Thames is equally applicable to the Ouse, the Nen, the Welland, the Glen, and the Witham; rivers flowing into the Wash, all of which rise either on or close to the escarpment of the Oolites, between the country near Buckingham and that east of Grantham, rocks which were once covered by the Chalk.

With minor differences, the same general theory equally

[1] See T. Codrington, 'On the Superficial Deposits of the South of Hampshire and the Isle of Wight,' *Quart. Journ. Geol. Soc.*, 1870, vol. xxvi. p. 528; and Sir John Evans, *The Ancient Stone Implements, &c., of Great Britain*, 1872, chap. xxv.

applies to all the rivers that run into the Humber. The early course of the Trent was established at a time when, to say the least, the Lias and Oolites overspread all the undulating plains of New Red Marl and Sandstone of the centre of England, extending, indeed, westwards. A high-lying anticlinal line threw off these strata, with low dips, to the east and west; and, after much denudation, the large outlier of Lias between Market Drayton and Whitchurch in Shropshire is one of the western results. Down the eastern slopes, the Trent began to run across an inclined plain of Oolitic strata.

The most important affluent of the Trent is the Derwent, a tributary of which is the Wye of Derbyshire. The Wye runs right across part of the central watershed of England, formed by the great boss of the Carboniferous Limestone of Derbyshire. At an old period of the physical history of the country, the valley north and west of Buxton had no existence, and the land there actually stood higher than the tops of the limestone hills to the east. An inclined '*plain of marine denudation*' stretched eastwards, and gave an initial direction to the drainage of the country. The river began to cut a channel through the limestone rocks; and as it deepened and formed a gorge, the soft Carboniferous shales in which the river rose were also worn away by atmospheric action, and streams from the north and west began to run into the Wye. By the power of running water, those valleys were deepened simultaneously and proportionately to their distance from the sources of the river; and the farther the Wye flowed, the more was its volume increased by the aid of tributary streams and springs. Thus it happens that the Wye seems unnaturally to break across a boss of hills, which, however, were once a mere slightly undulating unbroken plain of limestone.

When we come to the other rivers that enter the Humber north and west of the Trent, the case is more puzzling. The Oolites in that region were extensively denuded before the deposition of the Chalk; so that between Market Weighton and Kirkby-under-dale in Yorkshire, the Chalk is seen to overlap unconformably the Oolitic strata, and to rest directly on the Lower Lias. The Chalk, therefore, overspread all these strata to the west, and lay directly on the New Red Beds of the Vale of York, till, overlapping these, it probably intruded on the Carboniferous strata of the Yorkshire hills farther west. At this time the Oolites of the northern moorlands of Yorkshire seem to have spread westward till they also encroached on the Carboniferous slopes, the denuded remains of which now rise above the beautiful valleys of Yoredale and Swaledale, the strata, both Carboniferous and Secondary, having gentle eastern and south-eastern dips. These dips gave the rivers their initial tendency to flow south-east and east; and thus it was that the Wharfe, the Yorkshire Ouse, and the Swale, cutting their own channels, formed a way to what is now the estuary of the Humber, while the escarpments of the Chalk and Oolite were gradually receding eastward to their present temporary positions.

Returning now to the western-flowing rivers, we find that concerning them there is far less to be said. The Eden flows along the whole length of that beautiful valley, through various Permian and Triassic rocks, for nearly forty miles. Near Carlisle, a patch of Lias rests on the New Red Marls and Sandstones. Whether the whole length of the strata of the Vale of Eden was once covered by these newer rocks it is impossible to determine, but I believe that it must have been so to a great extent, and also that the Lias may have been covered by Oolitic strata. A great fault, east of the Eden, has thrown these formations down on the west, so that the faulted edge of the Permian beds now abuts on the high Carboniferous hills that form the eastern side of the valley. As these Permian and newer strata were denuded away, in time the present river Eden began to establish itself, and now runs through rocks in a faulted hollow, in the manner shown in

Fig. 129. What is the precise geological date of the origin of this great valley and its river course in their present form, is not easy to say; but it may approximately be of later date than the Oolites, and probably it is later than the Cretaceous and Eocene, or even than the Miocene epoch. So also with the other rivers of the west of England —the Lune, the Ribble, the Mersey, and the Weaver.

It seems that all the rivers of Wales, whether flowing through Cambrian, Silurian, Old Red, or Carboniferous rocks, have been busy scooping out their valleys ever since the close of that great continental epoch that ended with the influx of the Rhætic and Liassic sea across the Triassic salt lakes; and though these valleys were modified by ice, and partially filled with detritus, during a short episode in glacial times, the rivers afterwards re-asserted their rights to their old channels. All the important rivers, therefore, that flow east and west and north and south through the Silurian rocks of Wales, are in their origin approximately of the same age; and from Cader Idris to Pembrokeshire they have all cut their way through a tableland with minor undulations, while here and there remains a higher hill, the rocks of which were unusually

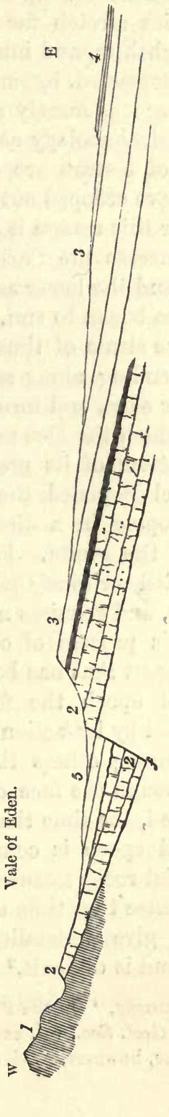


Fig. 129.—Section from the Cumbrian Mountains across the Vale of Eden to the Northumberland Coal-field.

1. Silurian Rocks. 2. Carboniferous Limestone. 3. Yoredale Rocks and Millstone Grit. 4. Coal-measures. 5. Permian Conglomerates, Sandstones, and Marls. f. Pennine fault.

hard. This old upland was indeed of great extent, and its relics stretch far and wide into the northern part of Denbighshire, and into Montgomeryshire and South Wales. All intersected by unnumbered valleys, to the ordinary observer it is merely a hilly country, while an eye versed in physical geology at once recognises that all the diversities of feature are due primarily to fluviatile erosions that have scooped out the valleys.

For this reason it also happens that the Dee now cuts right across the Carboniferous escarpment west of Erbistock and the lower area of the Permian strata; for when the Dee began to run, that escarpment had no existence, and the strata of those formations stretched further to the west, ending along some line now unknown in a sort of feather edge, and forming part of the great inclined plane over which the Dee ran at a level hundreds of feet above the bottom of its present valley. By-and-by, as the river channel deepened, the escarpment began to be formed, its face sloping in a direction at right angles to the general dip of the strata. Escaped into the low country of the New Red series of Cheshire, the history of the Dee becomes simple, and requires no special illustration.[1]

This process of ordinary fluviatile erosion is not the only agent that has been at work in Wales, for during the Glacial epoch the features, as before mentioned, were modified by ice-action, many lake-basins were scooped out, and among others the rock-bound basin of Bala Lake; and though the face of the country is always being slowly changed, the time that has elapsed since the close of the Glacial epoch is comparatively so short, that the large essential rocky features of the regions traversed by the rivers have since that time undergone no important alteration.

To give a detailed account of the river systems of Scotland is difficult.[2]

[1] Ramsay, 'On the Physical History of the Dee, Wales,' *Quart. Journ. Geol. Soc.*, vol. xxxii. p. 219.

[2] See, however, A. Geikie, *Scenery of Scotland*, ed. 2, 1887.

By referring to any good geological map of Scotland and the north of England, it will be seen that the country is intersected by two great valleys, running from north-east to south-west, namely, the 'Great Glen' or the valley of Loch Ness, running from Moray Firth to Loch Linnhe, and also the valleys of the Forth and Clyde. If we go farther south another valley traverses England from Tynemouth to the Solway Firth. The general strike of all the older formations of Scotland is more or less from south-west to north-east, and starting from the watershed of the north-west of Scotland between Loch Linnhe and Cape Wrath, it will be seen that almost all the larger rivers flow to the east and south-east, transverse to the general strike of the strata. In fact, like the Thames, they may be said to start from a great scarped watershed facing the Atlantic, and to run thence more or less in accordance with the general dip of the strata, or rather in conjunction with that, down a sloping plain of marine denudation, till they find their way into the sea or into the great valley of Loch Ness. Thus, in some degree, they follow the same general law that guided the east-flowing rivers of England; though traversing much more mountainous ground, they have cut their valleys in hard, greatly disturbed, and metamorphic strata.

South of the Great Glen, the rivers follow a north-east course, in Strath Dearn and Strath Spey, approximately parallel to the trend of the Great Glen, running in valleys probably excavated in lines of strike occupied by strata, less hard than the general mass of the country. The Tay does the same in the upper part of its course. South of Strath Spey, the rivers find their way east and south-east to the German Ocean; the Tay and the Forth from a high watershed that crosses Scotland from the neighbourhood of Fraserburgh on the east to Crinan on the west coast. To a great extent this is formed of hard granitic rocks with associated gneiss and schists, and it is high because of its power to resist denudation.

Like so many other rivers, the Tay has cut its way in old times over, and now through, a high belt of ground, that of the Sidlaw Hills just above the estuary; and the Forth, the Teith, and the Allan have in like manner breached that long range of volcanic hills known as the Ochils and Campsie Fells.

The whole of the estuary of the Forth and the greater part of the valley of the Clyde lie in an exceedingly ancient area of depression. That country is also covered more or less with Boulder-clay, and with later stratified detritus of sand and gravel which were formed in part by the remodelling of the Glacial drifts. These rivers ran in that area before the commencement of these deposits, and indeed for unknown ages before that period. But we have no distinct traces of those earlier epochs when we try to trace them as regards the history of the rivers of Scotland; and we know little besides this, that the Forth and the Clyde ran in their valleys long before the deposition of the Boulder-clay, and with other rivers resumed to some extent their old courses after the close of the Glacial epoch.

As of the rivers already mentioned, this may also be said of the Tweed, that we know nothing for certain of its history, except that its valley is of later age than the Old Red Sandstone and Carboniferous rocks. My own opinion is, that in general all the valleys of the south of Scotland may be said to have been formed contemporaneously with the valleys of the adjoining region of the north of England.

Of this we are certain, that some very ancient valleys in Scotland are older than the Old Red Sandstone, the deposition of which has more or less filled them with detritus, and they are now being re-excavated by running water. Taken as a whole, most of them may be said to be as old as the river-made valleys of Wales and Cumberland, for the disturbances which affected the Silurian and other Palæozoic formations of Scotland were coeval with those that first raised the mountains of Cumberland, Wales, and Ireland high above the level of the sea.

CHAPTER XXXII.

THE ORIGIN OF ESCARPMENTS, AND THE DENUDATION OF THE WEALD—GREYWETHERS AND THE DENUDATION OF THE EOCENE STRATA.

In the foregoing pages much has been said about *escarpments*. The origin of escarpments is generally the same, and they are nearly all marked by this peculiarity, that the strata dip at low angles in a direction opposite to the slope of the scarp (see Fig. 130). They are therefore generally quite different from sea-cliffs.[1]

Bordering the Weald of Kent and Sussex the Chalk hills of the North and South Downs form excellent ex-

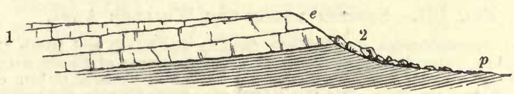


Fig. 130.—Section of Escarpment.

1. Strata with a low dip, *e* escarpment. 2. Detritus slipped from the escarpment down towards the plain *p*.

amples of escarpments; but the area itself is considerably diversified. Beneath the steep Chalk hills there is a valley formed by the Gault clay, beyond which, as at Leith Hill, there rises an escarpment of Lower Greensand. Below the slopes formed by this formation there is a clayey plain, excavated in the Weald Clay, which itself surrounds a

[1] See Whitaker, 'On Subaerial Denudation, and on Cliffs and Escarpments of the Chalk and the Lower Tertiary Beds,' *Geol. Mag.*, 1867 (reprinted).

nucleus of undulating sandy hills, formed by the Hastings Beds in the centre of this Wealden area. It is, in fact, a great amphitheatre, on the outermost rim of which the Chalk rises in bold escarpments. On the east it is bounded by the sea. There can be no doubt that the Chalk and the underlying formations of Upper Greensand, Gault, Lower Greensand, and Weald Clay originally extended across the whole area of the Weald for a breadth of from twenty to forty miles from north to south, and nearly eighty from east to west (Figs. 131 and 133). This vast mass, many hundreds of feet thick, has been swept away, partly by the wasting power of the sea, but chiefly by atmospheric agencies; so much so, indeed, that all the present details, great and small, of the form of the ground, are due to the latter. The main features are shown in the following diagram, the height of which is purposely exaggerated so as to bring them prominently before the eye.

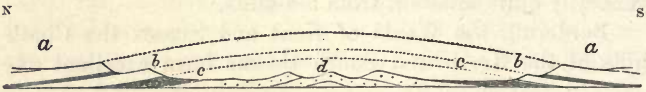


Fig. 131.—Section across the Wealden Area.

a a, Upper Cretaceous strata, chiefly Chalk, forming the North and South Downs, underlaid by Upper Greensand and Gault. *b b*, escarpment of Lower Greensand with a valley between it and the Chalk. *c c*, Weald Clay, forming plains. *d*, hills formed of Hastings Beds. The Chalk, &c. once spread across the country, as shown in the curved and dotted lines.

The idea that the Wealden area once formed a vast oblong bay, of which the Chalk hills were the coast cliffs, is exceedingly tempting; for, standing on the edge of the North Downs near Folkestone, and looking west towards Ashford, and south-west across the Romney Marsh, it is impossible not to compare the broad flat to a sea overlooked by bays and headlands, which the winding outlines of the Chalk escarpment, both of the North and South Downs, are sure to suggest. The same impression is conveyed, wherever one may chance to stand on the edge of the Chalk Downs, all the way from Folkestone to Alton and Petersfield, and from Petersfield to Eastbourne.

It is obvious, however, that the base of the Chalk and Upper Greensand all round the Weald from Folkestone to Eastbourne could not have formed a continuous shore line in recent times, if the area were depressed to *s s*, as suggested in the diagram (Fig. 132), for parts of it on the east are at the sea-level now; while other parts, along gently undulating lines at the bases of the North and South Downs, rise to more than 250 feet above that level.

Further, if the area had been filled by the sea, we might naturally expect to find traces of superficial marine strata of late date, as in some other parts of England, scattered across the surface between the opposite Downs. None of these traces exist. On the contrary, the underlying strata of the Cretaceous and of the Wealden series everywhere crop up and form the surface of the ground; except where here and there, near the Chalk escarpments, they are strewn with flints, the relics of the subaërial waste of the Chalk, or where they are covered by fresh-water sands, gravels, and loams of the ancient rivers of the country.

Therefore, the form of the ground in the Wealden area has been mainly brought about by atmospheric causes, and the operation of rain and running waters. One great effect of the action of the sea, combined with atmospheric

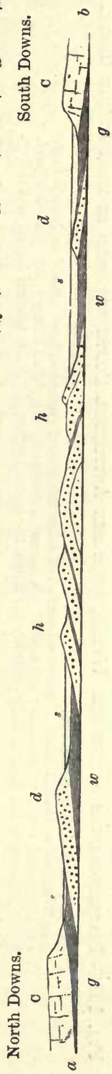


Fig. 132.—Diagram showing the General Effect of a Partial Submergence of the Weald.

c c, Chalk and Upper Greensand forming North and South Downs.
g g, Gault generally forming a vale.
d d, Escarpments of Lower Greensand.
w w, Weald Clay generally forming a plain.
h h, Central hills of Hastings Sand.
a b, Sea-level.
s s, Imaginary sea-level.

FIG. 133.—DIAGRAM-SECTION ACROSS THE WEALD, WITH THE ANTICLINAL CURVE RESTORED AS HIGH AS THE CHALK.

s s, The level of the present sea.
p p, The level of the old *plain of marine denudation*, after the dotted parts had been *planed* or denuded off.
c c, Chalk and Upper Greensand; *g g*, Gault; *s s*, Lower Greensand; *w w*, Weald Clay; *h h*, Hastings Sand.
Some portions of the Eocene Beds probably lay above the curved strata of Chalk marked in the dotted line.

waste, when prolonged over great periods of time, is to produce extensive *plains of marine denudation* like the line *b b*, Fig. 122, p. 347; for this combined result is to *plane off*, as it were, the asperities of the land, and reduce it to an average tidal level.

Suppose the old curvature of the various formations across the Wealden area to be restored by dotted lines, as in Fig. 133, which is very nearly on a true scale. Let the upper part of the curve be planed across, as shown in the figure, and let the newly planed surface, slightly inclined from the interior, be represented by the line *p p*. Toward this line, the various masses of the Hastings Sand *h h*, Weald Clay *w*, the Lower Greensand *s*, the Gault *g*, and the Chalk and Upper Greensand *c*, would crop up. Then, by aid of rain and running water, large parts of these strata would necessarily be cut away by degrees, so as to produce in time a new configuration of the ground. If it were not so, we might expect that the rivers of the Wealden area should all flow out at its eastern sea-border, through long east and west hollows, previously scooped out, where the ground is now low, by the assumed wasting power of the sea, towards which the long plains of Gault and Weald Clay now directly lead. But this, except with certain rivulets, is so far from being the case, that the river Beult rises only ten miles from the sea coast and flows westward. If, on the other hand, such a plain as *p p* once existed, it is easy to understand how the rivers in old times flowed from a low central watershed to the north and south across the top of the Chalk, at elevations at least as high as, and probably even higher than, the present summit-levels of the Downs.

Then, as by the action of running water, the general level of the inner country was being unequally reduced, so as to form tributary streams each cutting out its own valley, the greater rivers, augmented in volume by these tributaries, were all the while busy cutting and deepening those north and south channels through the Chalk Downs now known as the valleys of the Stour, the Medway, the Dart, the Mole, and Wey, which run athwart the North Downs, and the Arun, the Adur, the Ouse, and the Cuckmere, which flow southward through gaps in the South Downs. On any other supposition, it is not easy to understand how these channels were formed, unless they were produced by fractures or by marine denudation, of neither of which is there any proof. Through most of these gaps there are no known faults of any kind, and the whole line of the Chalk is singularly destitute of great fractures.

We get a strong hint of the probable truth of this hypothesis concerning the denudation of the Weald, in the present form of the ground. Thus after the formation of the marine plain *p p*, the Chalk, over a narrow belt, has been wasted backward all round the Weald, and now stands out as the bold escarpments of the North and South Downs. The soft clay of the Gault has been more easily worn away, and forms a hollow or plain between the Chalk and the Lower Greensand. The Lower Greensand, some portions of which are full of hard calcareous bands and ironstone, more strongly resisting denudation, forms a second range of scarped hills, overlooking the more easily wasted Weald Clay. This Clay makes a second and broader plain, from under which rise the subdivisions of the

Hastings Sands, forming the undulating hills of Ashdown Forest, and other places, in the broad centre of the low anticlinal curve. The absence of flints from nearly the whole of the Wealden area, excepting near the Downs, is easily explained by this hypothesis, for the original marine denudation had removed all the Chalk, except near the margin (see Fig. 133), long before the rivers had begun simultaneously to scoop out the valleys of the interior, and to cut the transverse valleys across the North and South Downs.[1]

It is believed that, excepting for a short distance along the coast, this southern part of England was not depressed beneath the sea during any part of the Glacial period. It has, therefore, been above water for a very long time. During the Miocene period it must have been subjected to much subaërial denudation. High up near the edge of the North Downs, however, certain fragmentary outliers of Crag, described by Professor Prestwich, are preserved in pockets of the Chalk at Lenham, Paddlesworth, and other places. These Pliocene Beds must have been deposited upon that old plain, and, indeed, the marine denudation, initiated perhaps in Eocene times, may have then been largely effected.

The 'Denudation of the Weald' has given rise to much theorising by distinguished authors, but it may now be said to be due to the subaërial erosion that followed the wide-spread marine action. Thus the outer crust of Chalk that once cased all the strata of the great anticlinal curve, having been *planed off*, and by subsequent elevation a tableland having been formed, the different rocks that cropped up to the surface of this plane were attacked by rain and rivers, and worn away so as to form by degrees

[1] The original sketch of these views was published in 1863, and in an enlarged form in 1864, in a second edition of this work. For details on the same subject, see Foster and Topley, *Quart. Journ. Geol. Soc.* 1865, vol. xxi. p. 443; and Topley, *Geology of the Weald*, 1875.

the hills and valleys of the district, including the great escarpments of the North and South Downs. The features have been modified at various periods since Eocene times; and during the Pleistocene period some of the Chalk valleys were deepened, and some 'coombes' may have been formed. Thus, as Mr. C. Reid has pointed out, the occurrence on the Downs, and elsewhere in hills of porous strata, of deep *dry valleys* in which no streams now exist, even after the heaviest rain, may be attributed to the former action of rain on frozen surfaces. The sheets of irregularly stratified rubbly flint-gravels and chalky-gravel (Coombe Rock) point to this kind of denudation in the Chalk Downs, and, together with their organic remains, they indicate Desert or Steppe conditions.

Though the Secondary and older Tertiary strata of England generally lie flat or dip at low angles, yet in certain instances they have been very considerably disturbed; for

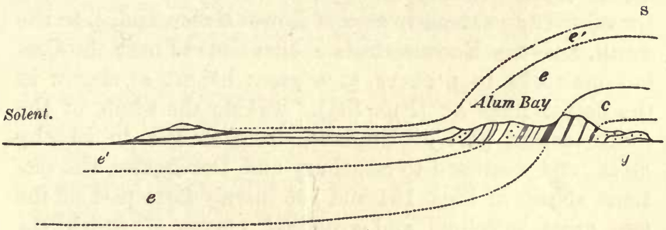


FIG. 134.—SECTION ACROSS THE ISLE OF WIGHT.

g, Lower Greensand; *c*, Chalk, etc.; *e*, Woolwich and Reading Beds, London Clay, Bracklesham and Bagshot Beds, and the overlying Oligocene Strata *e'*.

on a line which runs through the Isle of Wight and the Isle of Purbeck they stand nearly on end. From White Cliff Bay to Alum Bay, there is overlying the Lower Greensand *g*, a long range of Chalk hills, *c*, the strata of which dip towards the north, and are overlaid by the older Tertiary strata *e*, that is to say, the Woolwich and Reading Beds, the London Clay, the Bagshot and Bracklesham Beds, and the higher Fluvio-marine (Oligocene) divisions *e'* (see Fig. 70, p. 205). The whole pass under the Solent, as shown in the lower dotted lines $e e'$ (Fig. 134), and rise again on the mainland in Hampshire, a considerable portion of which is composed of subdivisions of the Eocene and Oligocene strata.

The same general relations of the Secondary and Eocene strata are seen in the Isle of Purbeck, as shown in the following section north of Kimeridge Bay (Fig. 135).

FIG. 135.—SECTION ACROSS THE ISLE OF PURBECK.

1. Kimeridge Clay. 2. Portland Sand. 3. Portland Stone. 4. Purbeck Beds. 5. Wealden sands and clays. 6. Lower Greensand, Gault, and Upper Greensand. 7. Chalk without flints. 8. Chalk with flints. 9. Woolwich and Reading Beds. 10. London Clay. 11. Bagshot Beds.

Now those disturbed strata of the Isle of Wight were deposited horizontally, and after disturbance, the Chalk, *c*, spread over an extensive area of Lower Greensand, *g*, to the south, and the Eocene strata *e* once spread over the Cretaceous rocks in a curve, at a great height, as shown in the dotted lines $e e'$ (Fig. 134). Taking the whole of the south-eastern part of England, from Suffolk to Beachy Head, and westward to Salisbury and Dorchester, the sections shown in Figs. 134 and 135 merely form part of the two great anticlinal and synclinal curves of which the Hampshire and London basins form parts. Here then in our Secondary and Tertiary rocks we get evidence, though in less degree, of the same kind of disturbance and denudation of which we have such striking proofs when we consider the structure in the western and north-western area of the countries which are composed of Palæozoic rocks. In the central part of England the Chalk and other strata, not having been so much disturbed, have necessarily not been so much denuded in height, but chiefly over their superficial extent from west to east.

Some of the strata in the Woolwich and Reading Beds and in the Bagshot series consist of sands, portions of which have become exceedingly hard by being cemented with silica. These formations, together with the Chalk, once spread much further to the west than they do now, because outlying patches of Eocene rocks occur here and there almost at the very edge of the great Chalk escarpment, as shown in Fig. 113, p. 335. It so happened that when the wasting processes took place that wore away both these formations from west to east, the softer clays and part of the sands of the Eocene strata were more easily removed than the harder rocky portions, and the result is that over large areas, such as Marlborough Downs, great tracts of Chalk are strewn with huge blocks of hard sandstone known as 'Greywethers.'[1] They are, however, in such

Fig. 136.—Section of Chalk Downs, Marlborough.

No. 1 represents the Chalk, Upper Greensand, and Gault; and 2 the overlying Eocene clays and sands; and the isolated blocks, lying on the Chalk, represent the thickly scattered masses of stone left on the lower ground after the removal by denudation of the softer parts of the Eocene, No. 2, and of underlying strata.

great request for building and paving purposes, that in the long run they will probably all be broken up and carried away. At the Prehistoric town of Avebury, immense masses of these 'greywethers,' set on end by a vanished people, stand in the ancient enclosure.

Sometimes these huge blocks lie on lower platforms of Chalk or Upper Greensand (see Fig. 136). Even on the plains of Gault or Kimeridge Clay, well out to the north or west of the escarpment, as for instance at Swindon, and also in the Wealden area, blocks angular or half-rounded lie in the meadows, marking the immense waste to which the whole territory has been subjected long after the close of Eocene times. They plainly tell that the Chalk and overlying Eocene beds once spread far across the plains

[1] See Ramsay, in *Geology of Parts of Wiltshire and Gloucestershire*, 1858; and T. R. Jones, 'History of Sarsens,' *Mag. Wilts. Arch. Soc.*, vol. xxiii. 1887, p. 122.

which the abrupt Chalk escarpments now overlook. These have been and are still being wasted back, for they are comparatively easily destroyed, but the strong 'greywethers' remain, and as the rocks on which they once lay were slowly wasted away and disappeared, these masses of tough and intractable siliceous stone gradually subsided to their present places.

Besides the name of 'greywethers,' they are also known as Sarsen stones, and Druid stones, and all the rude standing masses of Avebury and the larger roughly shaped blocks at Stonehenge, popularly supposed to be Druidical temples, have been left, by denudation, not far from the spots where they have since been erected into such grand old monuments by an ancient race.[1]

In Hertfordshire, near Watford and St. Albans, the pebbly Reading Beds have been cemented into a hard siliceous rock, known as 'Hertfordshire puddingstone;' and masses of this rock as well as greywethers are found in the Drifts on the Chiltern Hills, and sometimes in the valley-gravels of the Thames, whence they have been transported from their parent sources.

[1] The smaller stones at Stonehenge have been brought from a distance. They are mostly of igneous origin, and are believed by Mr. Fergusson to have been votive offerings. See also Maskelyne, *Mag. Wilts. Arch. Soc.*, vol. xvii. p. 159, Cunnington, *ibid.* vol. xxi. p. 141, and *Proc. Geol. Assoc.*, vol. vii. p. 138.

CHAPTER XXXIII.

SOILS.

The soils of a country necessarily vary to a great extent, though not entirely, with the nature of the underlying geological formations. Thus, in the highlands of Scotland the gneissic and granitic mountains are generally heathy and barren, because they are so high and craggy; any soil that is formed is rapidly washed away by rains, and the hard rocky materials come bare to the surface over considerable areas. Strips of fertile meadow-land lie chiefly on narrow alluvial plains, which here and there border the rivers. Hence the Highlands mainly form a wild and pastoral country, sacred to grouse, black cattle, sheep, and red deer.

Further south, Silurian rocks, though the scenery is different, produce more or less the same kinds of soil, in the broad range of hills that lies between the great valleys of the Clyde and Forth, and the borders of England, including the Moorfoot and the Lammermuir Hills, and the high grounds that stretch southwards into Carrick and Galloway. There, the rocks, being chiefly composed of hard, intractable, gritty, and slaty material, form but little soil because they are difficult to decompose. Hence the higher ground is to a great extent untilled, though excellently adapted for pastoral purposes. Where, however, the slopes are covered more or less with old Glacial-drifts and moraine matter, the soil, even high on the slopes, is deep, and the ground is fertile, and many beautiful vales intersect the country. Most of the rivers run through bare and solitary pastoral regions in the upper parts of their courses, gradually passing, as they descend and widen, into well-cultivated tracts and woodlands. On the eastern side of Sutherland the limit of cultivation on the hill slopes is marked by the occurrence of Glacial-drift, and by the fringe of Jurassic rocks bordering the sea-coast from Golspie to Helmsdale.

The great central valley of Scotland, between the metamorphic series of the Highland mountains and the Silurian strata of the southern uplands, is occupied by rocks of a more mixed character, consisting of Old Red Sandstone and of the Carboniferous series, intermixed with considerable masses of igneous rocks. The effect of denudation upon these formations in old times, particularly of the denudation and deposition which took place during the Glacial period, and the subsequent rearrangement of the ice-borne débris, have led to the covering of large tracts of country with a happy mixture of materials—such as clay mixed with stones, sand, and marl. In this way one of the most fertile tracts anywhere to be found in our island has been formed, and its cultivation for a century or more has been taken in hand by skilful farmers, who have brought the agriculture of that district up to the very highest pitch which it has attained in any part of Great Britain.

Through the inland parts of England, from Northumberland to Derbyshire, we have another long tract of hilly country, of fells and moors, composed of Carboniferous rocks, forming regions so high that, except in the dales, much of it is unfitted for ordinary agricultural operations.

The Derbyshire limestone tract, for the most part high and grassy, consists almost entirely of pasture-lands, intersected by cultivated valleys. On the east and west that region is skirted by high heathy ridges of Millstone Grit. North of the limestone lies the moss-covered plateau of Millstone Grit, called Kinder Scout; and beyond this, between the Lancashire and Yorkshire coal-fields, there is a vast expanse of similar moorland, intersected by grassy valleys. Still further north, all the way to the borders of Scotland, east of the fertile Vale of Eden, the country may also be described as a great high plateau, sloping gently eastward, through which the rivers of Yorkshire and Northumberland have scooped so many valleys.

The uplands are generally heathy, with occasional tracts of peat and small lakes ; but when formed partly of limestone, grassy mountain-pastures are apt to prevail, through which in places those 'blind roads' run northward into Scotland, so graphically described by Sir Walter Scott.[1] Here and there the deeper valleys are cultivated, dotted with villages, hamlets, the seats of squires, farms, and the small possessions of the original *Statesmen*.[2] Of this kind of land the Yorkshire dales may be taken as a type. Nothing is more beautiful than these dales, so little known to the ordinary tourist. The accidental park-like arrangement of the trees, the soft grassy slopes leading the eye on to the higher terraces of limestone or sandstone, which, when we look up the valleys, are lost in a long perspective ; the uppermost terrace of all sometimes standing out against the sky, like the relic of a great Cyclopean city of unknown date, as in the time-weathered grits of Brimham—these together present a series of views quite unique in the scenery of England.

The larger part of this northern territory is therefore, because of the moist climate of the hilly region, devoted to pasture-land, as is also the case with large portions of Cumberland and the other north-western counties of England. In the Vale of Eden, however, and along the southern shores of the Solway, the Permian and New Red rocks and the boulder-clays of that noble valley generally

[1] 'By which I mean the track so slightly marked by the passengers' footsteps, that it can but be traced by a slight shade of verdure from the darker heath around it.'—*Guy Mannering*, chapter xxii.

[2] See *Life and Letters of Sedgwick*, by Clark and Hughes, vol. i. p. 8.

form excellent soils, well watered by the river and all its tributary streams that rise in the adjacent mountains and high broad-topped fells. The higher mountain tracts of Cumbria are known to all British tourists for their wild pastoral character, intersected by exquisite strips of retired green alluvial valleys.

The same general pastoral character, which prevails in Cumberland and Westmoreland, is also observable in Wales. In that old Principality, and also in the Longmynd of Shropshire, there are vast tracts of elevated land, covered with heath, and therefore fit for nothing but pasture-land: but on the low grounds, and on the alluvium of the rivers, there is often excellent soil. The Vale of Clwyd, in Denbighshire—the substratum of which consists of New Red Sandstone, covered by Glacial drift, and bounded by Carboniferous rocks and high Silurian hills—is fertile, and wonderfully beautiful. The valleys of the Usk and the Wye are renowned for quiet and fertile beauty; but no inland river of equal volume in Britain surpasses the Towey in its course from Llandovery to Caermarthen, flowing as it does through broad alluvial plains, bounded by wooded hills, the plains themselves all park-like.

Taken as a whole, the eastern part of South Wales, Monmouthshire, Herefordshire, and parts of Worcestershire, occupied largely by the Old Red Sandstone, though hilly, and in South Wales occasionally even mountainous, form ground that is naturally of a fertile kind. This is especially the case in the comparatively low-lying lands, from the circumstance that the rocks are generally soft, and therefore easily decomposed; and where the surface is covered with drift, the loose material is chiefly formed of the waste of the partly calcareous strata on which it rests, and this adds to its fertility, for the soil is thus deepened and more easily fitted for purposes of tillage, while much of the land is dotted with noble woods and orchards.

In the centre of England, in the Lickey Hills, near Birmingham, and in the wider boss of Charnwood Forest, where the old Palæozoic rocks crop out like islands amid the Secondary strata, it is curious to observe that a wild character suddenly prevails in the scenery, even though the land lies comparatively low, for the rocks are rough and intractable, and stand out as miniature mountains. Much of Charnwood Forest is, however, covered by drift, and is now being so rapidly enclosed that, were it not for the modern monastery and the cowled monks who till the soil, it would almost cease to be suggestive of the England of mediæval times, when wastes and forests covered half the land.

If we now pass to the Secondary rocks that lie in the plains, we find a different state of things. In the centre of England, formed of New Red Sandstone and Marl, the soils are for the most part naturally far more fertile than in the mountain regions of Cumberland and Wales, or in some of the Palæozoic areas in the extreme south-west of England. When the soft New Red Sandstone and Marl are bare of drift, and form the actual surface, they decompose easily, and form deep loams, save where the conglomerate beds of the same series come to the surface. These conglomerates consist to a great extent of gravels, often barely consolidated, and formed of water-worn pebbles of various kinds, but sometimes chiefly of liver-coloured quartzite, like that of the Lickey Hills, and of siliceous and ferruginous sand. This mixture forms, to a great extent, a barren soil. Some of the old waste and forest lands of England, such as Sherwood Forest and Trentham Park, part of Beaudesert, and the ridges east of the Severn, near Bridgnorth, lie almost entirely upon these intractable gravels, or on other sands of the New Red Series, and have remained partly uncultivated to this day. As land, however, becomes in itself more valuable, the ancient forests are being cut down and the ground enclosed.

In the midland counties there are broad tracts of land composed chiefly of New Red Marl and Lias clay. The marl consists of what was once a light kind of clay, mingled with a small percentage of carbonate of lime; and when it moulders down on the surface, it naturally forms a fertile soil. A great extent of the meadow and pasture land in the centre and west of England is formed of these red strata, sometimes covered with Glacial deposits.

It is worthy of notice that the fruit-tree districts of England lie very largely upon red rocks, sometimes of the Old and sometimes of the New Red Series. The counties of Devonshire, Herefordshire, Worcestershire, and Gloucestershire, with their numerous orchards, celebrated for cider and perry, lie in great part on these formations, where all the fields and hedgerows are in spring white with the blossoms of innumerable fruit trees. Again, in Scotland, the plain called the Carse of Gowrie, lying between the Sidlaw Hills and the Firth of Tay, stretches over a tract of Old Red Sandstone, and is famous for its apples. The Lower and Middle Lias also furnish some famous fruit-growing districts, as at Evesham and Pershore, again near Cheltenham, and further south near Pennard Hill and Glastonbury, and in the vale of Marshwood in Dorsetshire.

The Lias clay in the centre of England forms a considerable proportion of our pastures and meadow-land, the stiff clay being especially adapted for grasses. Only the basement-portion of the Lower Lias, where limestones are developed, forms arable land of any extent. Thus much of the midland area is devoted to pastures, often intersected by numerous footpaths of ancient date, that lead by the pleasant hedgerows to wooded villages and old timbered farmsteads. When we pass into the Middle Lias, which forms an escarpment overlooking the Lower Lias clay, we find a very fertile soil; for its upper bed of Marlstone, as it is called, is much lighter in character than the more clayey Lower Lias, being formed of a mixture of clay and sand with a considerable proportion of ferruginous matter and carbonate of lime. The low flat-topped Marlstone hills, well seen in Gloucestershire and at Pennard in Somersetshire; the bold escarpment of Edge Hill, that slopes towards Banbury, are features whose declivities are usually marked by a strip of peculiarly fertile soil; and the country is dotted, as in Oxfordshire, with villages and towns with antique churches and handsome towers, built of the brown limestone of the formation. There the soil is often of a very ruddy colour.

Ascending the geological scale into the next group, we find the Oolitic rocks formed, for the most part, of beds of limestone, with here and there interstratified clays, some of which, like the Oxford and Kimeridge Clays, are of great thickness, and spread over large tracts of country. The flat tops of these limestone Downs, when they rise to considerable height, as they do on the Cotteswold Hills, were, until a comparatively recent date, left in an unenclosed state. Now they are used largely as pasture-land. They form a feeding-ground for vast numbers of sheep, of which the Cotteswold breed is noted. Hence, also, the origin of the woollen factories of Gloucestershire. In some parts we find these areas have been brought under the dominion of the plough, and on the Inferior and Great Oolite, and on the Cornbrash, we find many fields of turnips and grain. The broad flat belts of Oxford and Kimeridge Clay, that lie between the western part of the Oolite and the base of the Chalk escarpment, are in part in the state of grass-land, and in Wiltshire especially there are numerous dairy farms.

In the north of England the equivalents of the Lower Oolites form the broad heathy tracts of the Yorkshire moors, and the fertile Vale of Pickering is occupied by the Kimeridge Clay.

If we pass next into the Cretaceous series, which in the middle and south of England forms extensive tracts of country, we meet with many kinds of soil, some, as those on the Lower Greensand, being excessively siliceous, and in places intermingled with veins and strings of oxide of iron. Such a soil still remains in many places intractable and barren. Thus, on the borders of the Weald from Leith Hill to Petersfield, where there is very little lime in the rocks, there are thick plantations of fir, and many wide-spread unenclosed heaths, almost as wild and refreshing to the smoke-dried denizens of London as the broad moors of Wales and the Highlands of Scotland. These, partly from their height, but chiefly from the poverty of the soil, have never been brought into a state of cultivation. Running, however, in the line of strike of the rocks, between the escarpments of the Lower Greensand and the Chalk, there are occasionally many beautiful and fertile valleys rich in fields, parks, and noble forest timber.

These areas, between the slopes of the Lower Greensand (where present) and the escarpment of the Chalk, consist of long strips of stiff clay-land formed of the Gault, which, unless covered by drift or alluvium, generally produces a wet soil. It extends along a band of country from Dorset and the outlet of the Vale of Pewsey in Wiltshire, along the Vale of White Horse, and by the foot of the Chiltern Hills through the Vale of Aylesbury, and north-eastward into Bedfordshire. Much of it affords rich pasture-land, and in the Vale of Aylesbury, where the soil is lightened by sandy loams washed from the higher grounds, the land is exceedingly fertile.

In Kent, Surrey, and Sussex, the Weald Clay forms a damp stiff soil when at the surface; but is now cultivated and improved by the help of deep drainage. In many places there are beds of superficial loam, on some of which the finest of the hop-gardens of that area lie. Loamy brickearths occupy the low banks of the Thames and Medway, in Kent, and are famous for hop-grounds and cherry orchards, and for those extensive brick-manufactories so well known in the neighbourhood of Sittingbourne. Similar loams sometimes overlie the Kentish Rag (Lower Greensand), and fill great 'pipes' or fissures due to the dissolution of that rock.

The Hastings Beds form on the surface a fine dry sandy loam. Much of the country is well wooded, especially on the west, where there are still extensive remains of the old forests of Tilgate, Ashdown, and St. Leonards. Down to a comparatively late historical period, both clays and sands were left in their native state, partly forming those broad forests and furze-clad heaths that covered almost the whole of the Wealden area. Hence the name Weald or Wold (a woodland), a Saxon, or rather Old-English term, applied to this part of England.

The Chalk strata of the North and South Downs stretch far into the centre and west of England, and the same strata extend in a broad band, only broken by the Wash and the Humber, northward through Lincolnshire into Yorkshire, where they form the well-known Wolds. In their wildest native state, where the ground lies high, the Downs were probably, from time immemorial, almost bare of woods. There we find, as near Marlborough, some of the earliest evidences of human occupation and industry: in earthworks and other monuments, in old track-ways and ancient terraces of cultivation or lynchets.

Many of the slopes of the great Chalk escarpments on the North and South Downs in the West of England, on the Chiltern Hills and elsewhere, are, however, so steep, that the ground, covered with short turf, and in places dotted with yew and juniper, is likely to remain for long unscarred by the ploughshare. Such tracts afford good pasture for sheep.

In many places the surface of the Chalk, as already stated, is covered by accumulations of clay with flints, forming a stiff cold and sometimes very stony soil, on the higher grounds of Wiltshire, Buckinghamshire, and Hertfordshire, and also on the Chalk of Kent and Surrey. It has in places been left uncultivated, and forms commons, or furze-clad and wooded patches. The loam which accompanies it is occasionally used for making bricks, and this deposit naturally forms the more fertile tracts. In the east of England, as in Essex and Suffolk, the Chalk and Eocene strata are very largely buried under thick accumulations of Boulder Clay and Glacial gravels, which completely alter the agricultural character of the country.

Various Eocene formations occur on all sides of London. They are often covered by superficial sand and gravel. Through the influence of the great population centred here, originally owing to facilities for inland communication afforded by the river, this is now, in great part, a highly cultivated territory, there being many market-gardens in the Thames Valley above London. Here and there, however, to the south-west, there are tracts formed of the lower part of the Upper Eocene strata, known as the Bagshot Sands, which produce a soil so barren that, although not far from the metropolis, it is only in scattered patches that they have been brought under cultivation. They are still for the most part bare heaths, and being sandy, dry, and healthy, camps have been placed upon them, as at Aldershot, and they are used as exercise-grounds for our soldiers.

Higher still, above this Eocene series in Hampshire, lie the Oligocene or Fluvio-marine beds on which a large part of the New Forest stands, commonly said to have been depopulated by William the Conqueror, and turned into a hunting ground. To the eye of the geologist it easily appears that the wet and unkindly soils produced by the clays and gravels of the district form a sufficient reason why in old times, as now, this never could have been a cultivated and populous country; for the soil for the most part is poor, and probably the tract was native forest-land even in the Conqueror's day.

The wide-spreading Boulder-clay of Holderness, of Lincolnshire and other midland counties, and of Norfolk, Suffolk, Hertfordshire, and Essex, for the most part forms a tenacious soil, somewhat lightened by the presence of stones, and sufficiently fertile when well drained to produce rich crops of corn. In Suffolk and Essex this chalky Boulder-clay covers wide tracts of flat land, and was formerly much used as a dressing for other soils, and it forms an excellent soil in itself. In east Norfolk the calcareous loams of the 'Contorted Drift' form some of the most fertile tracts in the country.

The great plain of the Wash consists partly of peat on the west and south, but chiefly of silt. The whole country is traversed by well-dyked rivers, canals, drains, and trenches. The ground looks as level as the sea in a calm, broken only by occasional poplars and willows, and farmhouses impressive in their loneliness. Yet it is not without charms of a kind; as, when at sunset, sluice, and windmill, and tufted willows, combined with light clouds dashed with purple and gold, compose a landscape such as elsewhere in Western Europe may be seen in the flats of Holland. The same impression, in less degree, is made on the banks of the Humber, where the broad warped meadows, won from the sea by nature and art, lie many feet below the tide at flood.

Such is a very imperfect sketch of the general nature of the soils of Great Britain, and of their relation to the underlying rocks. We have seen that throughout large areas the character of the soil is directly and powerfully influenced by that of the rock-masses lying below. Rain, frosts, and the roots of trees and shrubs tend to loosen and break up the surface strata. It must be borne in mind, however, that the abrading agencies of the Glacial period have done a great deal towards commingling the detritus of the different geological formations, producing widespread drift soils of varied composition. This detritus is far from being uniformly spread over the island. In some districts it is absent, while in others it forms a thick mantle, obscuring all the hard rocks, and giving rise to a soil sometimes nearly identical with that produced by the waste of the underlying formation, and sometimes of mixed clay and erratic stones.

In considering the nature and origin of soils, the agency of the wind in drifting fine material far and wide must not be neglected. Nor must we overlook the influence of decaying vegetable and animal matter, and the action of earth-worms,[1] of moles and other burrowing animals, while recent researches tend to show that micro-organisms play a very important part in the soil.

[1] Darwin, *The Formation of Vegetable Mould*, 1881.

CHAPTER XXXIV.

INDUSTRIAL PRODUCTS OF THE GEOLOGICAL FORMATIONS—CONCLUSION.

To enter into detail upon the peculiar effect of geology on the industries of the various races or the populations of different districts would occupy far too much space, and only a mere outline of the subject can be given.

First, let us turn to the older rocks. In Wales, these consist to a great extent of slaty material. The largest slate quarries in the world lie in the Cambrian rocks of Caernarvonshire. One single quarry, that of Penrhyn in Nant-Ffrancon, is half a mile in length, and more than a quarter of a mile from side to side. Other quarries of equal importance collectively occur in the Pass of Llanberis, and there are large quarries in the same strata at Nant-y-llef, but none of these are of the same vast size. Important quarries also lie in the Lower Silurian rocks near Ffestiniog in Merionethshire, and there are large slate quarries in the Wenlock Beds, near Llangollen, and others of minor note scattered about Wales, but always in Cambrian or Silurian formations.

In Cumberland, the slates near Shap have been employed for making slate-pencils, while the green slates in the Borrowdale Series have been worked for roofing and building-purposes. The material composing the green slates is mainly fine volcanic dust, hardened by intense pressure, and rendered fissile by slaty cleavage.

This property in slates is due to great disturbance and lateral pressure, which have so re-arranged and modified the particles of the rock that the mass cleaves in parallel plates. This cleavage, as shown in Fig. 137, may sometimes correspond with the original bedding, but is otherwise quite independent of it.

In Scotland, in the small island of Easdale, in the Firth of Lorne, there are slate quarries which have been worked for many years, and produce a good coarse-grained slate; but they are of small importance compared

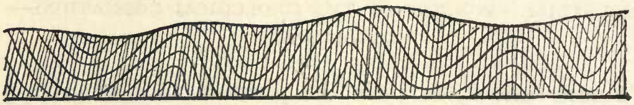


FIG. 137.—SECTION SHOWING SLATY CLEAVAGE. (J. G.)
The undulating lines=*bedding*. The straight lines=*cleavage*.

with the immense quarries of North Wales. Again at Ballachulish by Loch Linnhe, slates containing small scattered cubes of pyrites are largely worked.

Among the Devonian rocks slates have been obtained in Devonshire, but the more important are those of Tintagel and Delabole near Camelford in Cornwall.

In various districts of Great Britain the rocks abound in the ores of certain metals, which generally occurring in hilly regions, the workers in these mines are rarely congregated in numbers like the slate quarriers of North Wales, or the miners of coal and iron. The mineral wealth is derived in part from what are termed *lodes*, or fissures in the rocks, sometimes running for miles, and more or less filled with quartz, calc-spar, and ores of metals, which yield our chief supplies of copper, tin, zinc, and lead.

It is worthy of remark that these lodes or mineral veins are almost wholly confined to our oldest or Palæozoic rocks. The Devonian rocks are intersected by them in Devon and Cornwall, and these constitute the chief districts in England where copper and tin are found. In the Lower Silurian rocks of Wales, especially in Cardiganshire and Montgomeryshire, there are ores of copper, and many lodes highly productive in ores of lead, some of which are rich in silver. Gold also has been long known in Merionethshire, between Dolgelly, Barmouth, and Ffestiniog, sometimes, as at Clogau, in profitable quantity, but generally only in sufficient amount to show some reason for starting companies which occasionally lure unweary speculators to their loss. This Welsh gold is found in lodes generally in and near the base of the Lingula Flags, which in that area are talcose, and pierced by eruptive bosses and dykes of igneous rock.

In older times extensive gold mines were worked in Caermarthenshire at the Gogofau (*ogofau*, caves), near Pumpsant, between Llandovery and Lampeter. These excavations were first made open to the day in numerous irregular extensive quarryings and shallow caverns, where the gold-bearing quartz-veins and strings were followed into the hill. So extensive are these old works, that a minor valley was in the course of ages scooped out in the hill-side, and in the wood close by there is a deep artificial excavation now called *Cwm-henog*, which in English means Old-cave-valley. Later, lofty well-made galleries were driven, which cut the lodes deeper underneath. Gold was also found in washings of the superficial gravel, for more than a mile in length, on the banks of the river Cothy, and in the little upland valley that runs from the Gogofau towards the village of Cynfil Cayo. The well-cut galleries are Roman, but it has been surmised that the ruder caverns date from more ancient British times. The washing of the gravels for gold may probably be both of the old British and Roman ages, and for aught that is known the mines may have been worked in both ways in later times. It is not many years since the quartz veins were again systematically worked by an enterprising and skilful miner, but though gold was got, the result was not sufficiently profitable to warrant the continuance of the work. The huge excavations must have made ugly scars on the hills in the days when they were freshly worked, but time has healed them. The heaps of rubbish are now green knolls, and gnarled oaks and ivy mantle the old quarryings.

Traces of gold have been found in the older crystalline rocks of the Scottish Highlands, near Loch Earn Head, and in Sutherlandshire in the alluvial deposits of Kil-Donnan burn, near Helmsdale, as described by the Rev. J. M. Joass.

In the Carboniferous Limestone districts of North Wales, Derbyshire, Lancashire, the Yorkshire dales, and the moors of Northumberland and Cumberland, there are numerous lead-mines; and, as I have already said, lead-ore occurs in the older Silurian strata, as in South Wales, in the Isle of Man, and also in the Lead Hills in the South of Scotland, where lead, associated with silver, and even a little gold, has long been worked. Lead- and zinc-ores were formerly worked on the Mendip Hills, though little but the refuse left by old lead-miners is now utilised.

Various theories have been formed to account for the presence of ores in these rocks. Formerly, the favourite hypothesis was, that they were formed by sublimation from below, somehow or other connected with the internal heat of the earth; and the ores were supposed to have been deposited in the cracks through which the heated vapours passed. A great deal also has been said on the effect of electric currents passing through the rocks, and aiding in depositing along the sides of fissures the minerals which were being carried up by sublimation, or were in solution in waters that found their way into the fissures. It is, however, probable that the ores of metals in lodes have generally been deposited from solutions. We know that water, especially when warm, can take up silica in solution and deposit it, as in the case of the Geysers in Iceland; and we also know that metals may, in some states, be held in solution in water, both warm and cold. Chemists have detected minute quantities of silver, gold, and copper in solution in sea-water, and copper has been found in the thermal waters of Bath. We must remember that when the lodes or cracks were originally formed, those parts of them that we explore were not so near the surface as we now see them; but in a great many cases they lay deep underneath, covered by thousands of feet of rock that have since been removed by denudation. They were probably, in all cases, channels of subterranean filtration, both in their upper portions that have been removed by denudation, and in the parts originally deeper that now remain. It is certain, also, that these subterranean waters were warm, seeing that they sometimes lay deep in the interior of the earth, and came within the influence of internal heat, whatever may be its origin. If so, it is all the more likely that the ores which we meet with in these cracks or lodes were formed by infiltration of solutions, followed by deposition; for strings of copper, lead, and tin, for example, occur in the mass, just in the same way that we find mixed with them veins of carbonate of lime or quartz. This being so, then, just as the lime and silica may have been derived from the percolation of water through the rocks that form the 'country' on each side of the lode, so the metalliferous deposits seem to have been derived from metalliferous matter minutely disseminated through the neighbouring formations. We are, however, still in the dark as to many of the conditions under which the process was carried on.

Ores of iron are common in lodes, and in hollows or pockets, in the limestones of the Devonian and Carboniferous periods. In North Lancashire, in the Furness district at Ulverston, rich deposits of hæmatite lie among the joints and other fissures of the Carboniferous Limestone, and often fill large ramifying caverns deep underground.

In the Coal-measures, however, we have our greatest sources of mineral wealth, because they have been the means of developing other kinds of industry besides that which immediately arises from the discovery of the minerals which the Coal-measures contain. In the great coal-fields of this formation occur almost all the beds of coal worth working in Britain.[1] The only noteworthy exception is the Oolitic coal of Brora, in Sutherlandshire, and that is poor compared with the Carboniferous coal. Various estimates have been made concerning the probable underground extent of our Coal-measures and the duration of our coal. The estimates of duration vary from about 250 to 1,250 years. Much depends upon the depth at which coal can be worked, and also on the extent of the concealed Coal-fields. The finding of Coal-measures, with workable Coal, under the Cretaceous and Jurassic rocks at Dover, is of great interest.

The iron-ore from the Coal-measures is an impure argillaceous carbonate of iron, known as clay-band or clay-iron-stone. Besides coal and iron, the Coal-measures yield fire-clays of considerable value in the manufacture of crucibles and fire-bricks. During the past forty years the amount of iron-ore obtained from the Coal-measures has greatly decreased, and that from the Secondary strata has so increased as to yield about two-thirds of our supply.[2]

A great deal of valuable iron-ore has been obtained from the Lower Lias in Lincolnshire, and especially from the Marlstone of Yorkshire and Leicestershire. The result, in the Cleveland district of Yorkshire, has been the rapid growth of the enterprising port of Middlesborough on the Tees.

The Northampton Sands of the Oolites also yield large quantities of brown iron-ore, and towns like Wellingborough and Kettering have greatly developed in consequence. It must not, however, be supposed that ironstone is everywhere plentiful in that formation, nor yet in the

[1] *Report of the Royal Coal Commission*, 1871; R. Meade, *Coal and Iron Industries of the United Kingdom*, 1882; Hull, *Coal-fields of Great Britain*, ed. 4, 1881.

[2] J. D. Kendall, *Iron-ores of Great Britain, &c.*, 1893.

Marlstone, and far less in the Lower Lias; it is of local distribution, though iron-ore like that of Cleveland has been found in the Middle Lias of Raasay. In the Corallian rocks of Westbury, in Wiltshire, iron-ore has been worked for many years, and similar beds occur at Abbotsbury, in Dorsetshire.

In old times, in the Weald of the south of England, a considerable amount of iron-ore used to be mined and smelted with wood or charcoal, before the Coal-measures were worked extensively, and when the Weald was covered to a great extent with timber. Then the chief part of our iron manufactures was carried on in the south-east of England. Indeed, late in the last century, there were still iron-furnaces in the Weald of Kent and Sussex. The last furnace is said to have been at Ashburnham; and here and there we may even now see heaps of slag overgrown with grass, and the old dams that supplied the water to drive the water-wheels that worked the forges. It is said that cannon used in the fight with the Spanish Armada came from this district; and the rails round St. Paul's and other churches of the time of Sir Christopher Wren were forged from the Wealden iron.

There are some other geological formations which afford materials for manufactures other than coal and ores of metals. Thus, in the south-west of England, in the granitic districts of Devon and Cornwall, a great proportion of the finer kinds of clays occur, which are used in the potteries of North Staffordshire and elsewhere for making stoneware and porcelain. The natural decomposition of the felspar in the granite affords the substance known by the name of Kaolin, or China Clay, from which all the finer porcelain clays are made. This felspar consists of silicates of alumina, and soda or potash. The soda and potash are comparatively easily dissolved, chiefly through the influence of carbonic acid in the rain-water that falls upon the surface; and the result is that the granite decays to a considerable depth. In some cases, as at St. Austell, granite might for a depth of twenty feet or more be easily dug out with a shovel.

In the Eocene Beds of Bovey Tracey in Devonshire, and again in the neighbourhood of Poole, in Dorset, there are important beds of pipe-clay, great quantities of which are exported into the Pottery districts. But in addition to clay, the Chalk is brought into requisition to furnish its quota of material for the manufacture of various kinds of earthenware. The flints that are found embedded in the Chalk, chiefly in layers, are also transported to the Potteries, and ground up with the aluminous portions of the clay, since it is sometimes necessary to use a certain proportion of silica in the manufacture of porcelain.

Chalk-flints have also been largely used at Brandon and some other places for the manufacture of gun-flints.

Many other formations, such as the New Red Marls, are also of use when clay or marl is required for the manufacture of bricks. The Liassic and Oolitic strata include great formations of clay, such as the Lias Clays, Fullers' Earth Clay, Oxford and Kimeridge Clays; there is also the Weald Clay, and the Gault belonging to the Cretaceous strata. Again, the Woolwich and Reading Clays, the London Clay, and other Tertiary clays, are extensively used for brick and tile making. The Boulder clay is sometimes used in brick-making, and in the Eastern counties sun-dried bricks, known as 'clay-lumps,' are made from Boulder Clay mixed with chopped straw. The brickearths of the river valleys—as along the borders of the Thames—are largely used for brickmaking, for, consisting of loam, they are peculiarly well adapted for the purpose.

An abundance of material is found in all of these formations for the manufacture of bricks, roofing-tiles earthenware pipes, and so on; and it is interesting to observe how in this respect the architecture of the country is apt to vary according to the nature of the strata of given areas. In Scotland and the north of England, where hewable stone abounds, almost all the houses are built of sandstone or slaty rock, grey and sombre; in many of the Oolitic districts they are of limestone, and generally lighter and more graceful, and the buildings are sometimes roofed with stone tiles; while on the Red Marls, Lias, and in the woodland area of the Weald we have still the relics of an elder England in those beautiful brick and timbered houses that speak of habits and manners gone by. Near Bridgewater the 'Bath bricks' are manufactured from the alluvial silt of the tidal river Parret.

In the Upper Lias clay near Whitby in Yorkshire lumps of jet are found. This locally leads to a not unimportant branch of manufacture, though, owing to the demand, much jet is imported from abroad.

The glass-sand used in this country is derived from the Eocene Beds of Headon Hill, in the Isle of Wight, from the Lower Greensand near Godstone in Surrey and near Hartwell in Buckinghamshire, and from the sand-dunes on the borders of the Bristol Channel. Glass-sands must be remarkably pure in quality, being formed of fine white siliceous sand.

A large amount of hydraulic lime and cement is manufactured from the bands of limestone and cement-stones of our Lower Lias. These limestones are not pure carbonate of lime, but are formed of an intermixture of carbonate of lime and aluminous matter. It is found by experience that the lime from this kind of limestone is peculiarly adapted for setting under water. Hence the Lias lime has always been largely employed in the building of piers and other structures that require to be constructed under water. Cement-stones are also found in other formations, such as the Kimeridge Clay, and they were formerly obtained from the London Clay at Harwich and other parts of England. Lime or cement made from these rocks is known as 'Natural,' in distinction from the Artificial or Portland Cement, which is largely made from a mixture of Chalk and Medway mud, or of mixtures of other suitable materials.

The chief building-stones of our country, of a hewable kind, are the limestones of the Oolitic rocks, the Magnesian Limestone, the Carboniferous sandstones, and the sandstones of the New Red series. The Caradoc Sandstone, also, in Shropshire near Church Stretton, yields a good building-stone. The Oolitic building-stones include those from the Isle of Portland and the neighbourhood of Bath. St. Paul's and many other churches in London were built of Portland Stone, and the quantities of rejected stones in the old quarries show how careful Sir Christopher Wren was in the selection of material. The Bath Stone also affords a beautiful building-material, a yellowish oolite, which comes out of the quarries in blocks of great size, and is easily sawn and hewn into shape. Nearly the whole of Bath has been built of this stone, and it has been largely used in Westminster Abbey and other buildings in London. Excellent building-stones are also obtained from the Inferior Oolite, especially from the Cotteswold Hills, in the neighbourhood of Cheltenham and Painswick; also at Ham Hill and Doulting in Somerset, at Weldon in Northamptonshire, and at Stamford, Ketton, and Ancaster in Lincolnshire.

In England the Magnesian Limestone is extensively quarried for building-purposes. It is of very varied qualities—sometimes exceedingly durable, resisting the effects of time and weather, and in other cases decomposing with considerable rapidity. The Houses of Parliament were chiefly built of this stone. In districts where it occurs, in Nottinghamshire and Yorkshire, there are churches, and castles such as Conisbro', built of it, wherein the edges of the stones are as sharp as if fresh from the mason's hands. You can see the very chisel-marks of the men who built the castle, in days possibly before, but certainly not long after, the landing of William the Conqueror.

The Carboniferous Limestone, though not a freestone, is exceedingly durable. The Menai bridges were built of it. In Caernarvon Castle the preservation of this limestone is well shown. Devonian Limestone is largely used for building-purposes in South Devon. Sandstone, though durable, is rarely so good as certain limestones, which, being somewhat crystalline, and sometimes formed to a great extent of Encrinites, also essentially crystalline in structure, have withstood the effect of time. The New Red Sandstones being cemented by calcareous as well as ferruginous matter are liable to decay: a notable example of which was seen in Chester Cathedral before its restoration. The Sandstones of Grinshill, north of Shrewsbury, and those of the Peckforton Hills and Delamere Forest have furnished much building-stone.

The Carboniferous Sandstones in Lancashire, Derbyshire, Yorkshire, and in Wales and Scotland, afford large quantities of admirable building and paving material, which has been used almost exclusively in the building of Leeds, Edinburgh, Glasgow, and many other towns. Some of it is pale in tint, is easily cut by the chisel, and may be obtained in blocks of immense size. But in some of the beds there is much diffused iron, not visible at first sight, that in the course of time, as it oxidises, produces stains which discolour the exterior of the buildings. The Lower Carboniferous Sandstones of Craigleith and Granton, near Edinburgh, have been extensively used for building-purposes.

Basalts like the Dhu Stone of Clee Hill, and the Rowley Rag, and other hard and tough rocks, such as the quartzite of Hartshill, the granite of Mount Sorrel, also the Carboniferous Limestone, are largely utilised for road-metal; and the Guernsey diorites and syenites are quarried for kerbstones.

In Devonshire and Cornwall, in the Channel Islands, on Shap Fell in Westmoreland, and in Scotland, chiefly near Aberdeen and Peterhead, granites are largely quarried. They do not come into use as ordinary building-stones, except in such districts as Aberdeen, where no other good kind of rock is to be had. The granite of the Ross of Mull has also been polished for ornamental purposes. The Serpentine of Cornwall and Anglesey, and the Marble of the Carboniferous Limestone of Derbyshire and of the Devonian Limestone of Devonshire, yield beautiful materials for ornamental purposes. The Purbeck Marble is now but rarely obtained.

The rock-salt of Worcestershire and Cheshire lies in the New Red Marl, and the same formation yields the greater part of the gypsum or alabaster quarried at Newark-on-Trent and other places in England, though some also occurs in the Permian Marl of Yorkshire.

I have attempted to give an idea of the general physical geography of our country, both in ancient and modern times, as dependent on its geology. The somewhat arduous task is now completed. It is, after all, but a sketch of a large subject; but, with all its faults and omissions, this is the first work in which an attempt has been made to trace in detail the connection between the Physical Geography of old epochs in Britain and the features of land and water of the present day. Right or wrong in some of the questions raised, it is the work of one who, through more than half a lifetime, has

> 'pry'd through Nature's store,
> Whate'er she in th' ethereal round contains,
> Whate'er she hides beneath her verdant floor,
> The vegetable and the mineral reigns;
> Or else he scans the globe—those small domains,
> Where restless mortals such a turmoil keep,—
> Its seas, its floods, its mountains, and its plains.'

Let the reader learn from it what he can, and judge of the result.

INDEX.

[WITH BRIEF EXPLANATIONS OF SOME TERMS.]

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