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POPULAR

PHYSICAL GEOLOGY.

BY

J. BEETE JUKES, M.A., F.R.S., M.R.I.A.;

PRESIDENT OF THE DUBLIN GEOLOGICAL SOCIETY, LOCAL DIRECTOR OF THE GEOLOGICAL SURVEY OF IRELAND, AND FELLOW OF THE GEOLOGICAL SOCIETY OF LONDON; AUTHOR OF 'EXCURSIONS IN NEWFOUNDLAND,' 'NARRATIVE OF THE VOYAGE OF H.M.S. FLY,' ETC.

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TO
SIR H. T. DE LA BECHE, C.B., F.R.S.,
ETC. ETC. ETC.,

DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEY OF THE UNITED KINGDOM, AND
OF THE METROPOLITAN SCHOOL OF SCIENCE.

MY DEAR SIR HENRY,

The publication of this little Book gives me the opportunity, by dedicating it to you, of making a public acknowledgment of the uniform kindness and friendship I have received at your hands. I trust you will accept it as a token of my gratitude.

Much indeed of what knowledge it contains was derived from your teaching or acquired under your auspices, and therefore rightly belongs to you.

I have served now nearly seven years under your orders; allow me to hope that for very many more I may still remain

Your attached friend,

And faithful officer,

J. BEETE JUKES.

P R E F A C E.

THERE is not much original matter in this little book, taking original matter in the sense of *new facts*. The object aimed at, was to describe the common facts and principles of Geology, in a clear and concise manner, without entering too much into the detail of the observations by which those facts have been discovered, or on which those principles have been established. Its subject is confined to Physical Geology, because that is the branch of the Science with which alone I can claim a practical acquaintance, or on which I can be entitled to form an independent opinion. It is hoped that the Palæontological

branch of Geology may hereafter be treated of by one who is a thorough master of that portion of the subject.

My excuse for putting forth an elementary work on Geology at all, must be, that there can hardly be too many elementary books which are the results, more or less completely, of actual experience, and not the mere compilation and compression of other books. I recollect, when leaving school for college, being advised by an eminent scholar to read as many *different grammars* as possible. Not that it was supposed that any of them would contain any large amount of matter that was not to be found in all the rest, but that, by the different order and arrangement of the different writers, the matter was looked at on all sides and in every light. The mere variations in the turns of expression, or the terms of description, as well as in the collocation of parts, may make one thing more intelligible to one person and another to another.

There is one feature, however, on which I may be allowed perhaps to speak rather more boldly; and that is the illus-

tration of this little work. It was the expressed wish and desire of the publisher to have illustrations that should be of artistic merit as well as of accurate illustrative character. For this purpose I had recourse to the talents of my friend and colleague on the Irish Survey, Mr. G. V. Dunoyer, who unites the skill of the artist with the knowledge of the geologist. I think I may confidently appeal to the eyes of the Reader for the goodness of the result.

ERRATA.

Page 50, line 17, *for* carburet, *read* carbonate.

Page 63, line 2, *for* the mountain-like walls, *read* the mountain, like walls.

Page 94, Table, in analysis of Analcime, read, in Silica column, 55.2.

Page 208, line 3 from bottom, "many" should be at the beginning of the line instead of at the end.

Page 281, line 1, *for* inland, *read* inclined.

Page 301, line 2, *for* rage, *read* large.

DESCRIPTION OF THE PLATES.

PLATES I., II.

I. Falls, on the River Exploits, Newfoundland (Frontispiece).

II. Buchan's Island, on the River Exploits.

These two Plates taken together are intended to illustrate the sawing or grooving action of rivers in deepening their own beds. The present Falls are about a mile above the island, which is an isolated rock in the middle of the river; in the intermediate space the river flows in a narrow ravine, of the same depth as the height of the island. It is remarkable that the Falls are now divided into two by an island, which, as they cut back the rocks and recede up the river, will probably be left standing as an isolated pillar, like Buchan's Island. From my own sketches. See page 10.

PLATE III.

Baginbun Head, on the coast of Wexford, was selected as a picturesque example of a worn and indented coast, evidently pro-

duced by the erosive action of the sea-breakers on rocks of unequal hardness, or placed in varying positions, so as to oppose an unequal resistance to their action. See page 15.

PLATE IV.

Likewise illustrates the erosive action of the sea, a kind of approximate date being afforded by the nearly entire destruction of a human work. The top of the cliff, in the centre of the picture, is occupied by the remains of a double entrenchment, which could never have been thrown up for the purpose of defending the few feet of ground now included between it and the vertical cliff. The rock is hard gritstone and slate, yet we see that the action of the breakers has destroyed and removed a considerable block of land thus composed, *since* the time when this old embankment was thrown up. It is called Doonsorske Rath,—*rath* being the name for the common *circular* embankments so often seen in Ireland. It is at Carrigadda Bay, between Cork Harbour and Kinsale. See page 15.

PLATE V.

Is a composition by Mr. Dunoyer, from sketches and recollections of the Mitchelstown caves (county Cork) to illustrate the formation of stalactites and stalagmites. See page 29.

PLATE VI.

Sketch of a gravel-pit, to illustrate the way in which fine and

coarse gravel are interstratified, and the occasional regularity of the beds and the high angle at which these coarse materials are thrown down. The two latter characters were more than unusually prominent in the locality where the sketch was taken. See page 36.

PLATE VII.

A sketch of a cliff in the Old Red Sandstone at Ballyhaek, county Wexford, on the east side of the Waterford estuary. It shows the usual characters of a sandstone and conglomerate, and, in conjunction with the last Plate, the varying manner in which sand and pebbles are accumulated. See pages 36 and 39.

PLATE VIII.

Sketch of a quarry in the Oolite at Minchinhampton, in Gloucestershire, drawn by Mr. Dunoyer, from a rough sketch of my own. It illustrates what is called "false bedding" or "oblique lamination," the varying inclinations and directions namely assumed by the minor layers in the beds or strata of some kinds of rock. See page 41.

PLATE IX.

This very remarkable example was sketched by Mr. Dunoyer in a quarry near Mitchelstown, county Cork. The Mountain Limestone there contains layers of chert nodules. Its beds

have been bent by disturbing forces into regular arches, subsequently to which movement they have been affected by "cleavage" (represented by the fine lines crossing the face of the rock at a high angle), and this cleavage has so acted on the chert nodules as slightly to alter their shape, and *produce* them along its direction. See pages 51, 132, and 160.

PLATE X.

Sketch of a cutting in the side of the Dublin and Drogheda railway, near Malahide; it illustrates both the regular stratification of the Limestone, represented by the parallel lines which traverse the rocks at an angle inclining gently from the spectator; and the regularity of the "joints," which are found in all rocks, and which in this case produce the square corners and angles which the outline of the cliff is seen to present. See page 54.

PLATE XI.

Carnivan Head, county Wexford, shows the way in which regularly bedded rocks are often made up of alternating strata of different materials,—in this case conglomerate, sandstone, and shale. The hard sandstone beds are seen to project, like mouldings in relief, on the face of the cliff. See page 55.

PLATE XII.

Is from a rough sketch of my own, taken in a ravine near Santa

Cruz, Teneriffe. It illustrates the alternation of masses of rudely columnar basalt (old lava) with beds, which when fine-grained are singularly regular, and are composed of water-worn materials,—pebbles and sand derived from volcanic rocks. In the drawing, both the upper bed of columnar basalt and the under one, the surface of which forms the floor of the ravine and passes under the base of the cliff, are represented as much too regularly columnar. In reality the columns were very rude and irregular for the most part. The interposed stratified material however was quite as regular as represented in the drawing. See page 64.

PLATE XIII.

Is likewise from a rough sketch of my own, giving merely the outline and principal features of the little Island of St. Paul, in the Indian Ocean, taken from the anchorage. The sketch given in the Admiralty Chart was taken by Mr. Evans from the south or left-hand corner of the drawing. It is a well-known whaling ground, and two whales were basking in the anchorage when we landed. See page 67.

PLATES XIV., XV.

Are from sketches by Mr. Dunoyer on the Dundalk and Enniskillen Railway. They illustrate the way in which dykes and veins of igneous rock intrude among aqueous and stratified

rock. In this case the stratified rock is the Mountain Limestone.

In Plate XIV. the centre of the drawing is occupied by a broad vertical dyke of Greenstone, having in places a globular or spheroidal structure, which has filled up a chasm or rent formed in the Mountain Limestone beds. On the right-hand side of the picture is seen an oblique fault, or line of fracture, along which the thick-bedded limestones traversed by the dyke have slid down, so as to come opposite some much thinner-bedded rocks. This fracture was probably caused subsequently to the production of the dyke, or it would itself have had intruded into it some of the igneous rock.

In Plate XV. the three figures on the cliff to the left of the centre of the drawing, stand on a horizontal mass of Greenstone, which at first sight seems to be interstratified regularly with the beds, but which on being traced to the right is seen to split into two, one part passing into a thin bifurcating vein, that shortly ends, while the other cuts up right across the beds, and ultimately disappears at the top of the cliff: how much higher it extended into the beds that once existed above, we have of course no means of ascertaining. The place of a few of these beds is seen to be occupied by a few feet of "drift" gravel and sand, forming a soft, incoherent bed along the top of the cliff. See pages 62, 69, 75.

PLATE XVI.

Sketch of a small Granite Quarry in the county Carlow, showing the regularity and parallelism of the "joints" traversing that rock, and the smoothness of the faces caused by those natural planes of division. See page 113.

PLATE XVII.

Sketch of some rocks on the north side of Ringabella Bay, at the mouth of Cork Harbour. It illustrates the jointing and cleavage of stratified rocks, and is described at page 131, which see.

PLATE XVIII.

Sketch of some slate and gritstone rocks at Garrylucas Strand Old Head of Kinsale, county Cork. It illustrates the remarkably contorted positions often seen in stratified rocks. Near the left hand of the picture is seen a small fault, bringing down the two thick bands of gritstone against some thin-bedded rocks. The cliffs are seen to be capped by a bed of drift sand and gravel, about five feet in thickness. See page 160, etc.

PLATES XIX., XX.

These Plates are from two sketches by my late uncle, Mr. H. W. Jukes.

Plate XIX. represents Matlock, as seen from the escarpment of the Millstone Grit on the east of the Wirksworth road. The high ground on the left of the drawing is the Mountain Limestone, the beds of which dip to the east (or to the right of the spectator), and are cut through by the river Derwent, so as to form the High Tor and the cliffs in the centre of the drawing, just before they become buried by the soft beds of the Limestone Shale, which compose all the low ground and central valley. These soft beds are covered again by the hard rocks of the Millstone Grit, which form the crags from which the view is taken, and all the high ground on the right of the picture.

Plate XX. is a view taken in the wild scenery of Kinder Scout, in the north of Derbyshire. The Limestone Shale here lies in nearly horizontal beds, in which the deep valleys and ravines are scooped out, while the Millstone Grit, reposing on it, forms the rough crags of the mountain summits, and the tabular mass on the right of the drawing. In the course of two copyings, the crags in the distance on the left have become transformed into trees or bushes, somewhat to the detriment of the true effect, as the tops of the hills are occupied entirely by peat-bogs and crags of rock. See page 311.

POPULAR GEOLOGY.

Part II.

ELEMENTARY FACTS AND PRINCIPLES.

CHAPTER I.

HOW SAND, GRAVEL, CLAY, AND MUD ARE FORMED.

I do not know that we can commence an elementary book on Geology in a better way than by asking the reader if he knows *what sand is*. Because any one who thoroughly understands the origin and nature of common sand, whether it be found in the gravel-pit, in the river-bed, or be “the ribbed sea-sand” of the shore, has made no despicable commencement in the study of the science.

If the reader will examine a handful of sand by the aid of a lens, he will find that it is composed of grains or

minute irregularly-shaped particles of a hard, shining, often semi-transparent, substance. These particles are, if not round, very much *rounded*, often having on the surface a rubbed appearance, as if they had been worn and ground against each other.

As to river or sea sand, it is obvious that this rubbing must actually have taken place, because, as the moving water must frequently wash the sand about and roll it onwards in its course, the particles must be constantly exposed to friction against each other, or against whatever substance it may be that lies at the bottom of the water. It is clearly possible therefore that all river or sea sand may have been produced, or brought into the state of sand, by the action of the running or moving waters tearing away fragments of rock, breaking them up into constantly diminishing particles, and, by perpetual friction and rolling, grinding those particles into small rounded grains.

If this mode of formation be true for all sand found now beneath or on the margin of any moving water, it is, *à priori*, highly probable that all sand whatever, even that of the wide deserts of Sahara, the sands of Arabia, or those of the centre of Australia, have been thus formed.

If we come to consider of it, indeed, there appears to be

no other at all likely method by which sand could in any case be formed, unless it were originally created as sand, such as we now find it*.

Let it be taken for granted then, for the present, as the reader sees its great probability now, and will be quite convinced of its truth hereafter, that all sand was produced by the action of moving water on solid rock.

It is however by no means necessary to suppose that the water always detached the sand directly from the rock *as sand*, that is, in small grains. On the contrary, if we examine the action of moving water now, whether we go to the rapids and cataracts of rivers or to the breakers of the sea battering against a rocky coast, we shall everywhere see large blocks of rock lying about, often but newly detached from their original site, with all their angles sharp

* In commencing the study of a science, it is often useful to the student to have every stumbling-block cleared out of his path, however little may be the likelihood that he should fall over it. If any one therefore chooses to start as a difficulty the supposition that sand may have been created as we now find it, I have only to remind him that, if so, ever since its creation the action of water must have been tending to wear and waste it away, and grind it into powder. Given only 6000 years of this action, and there could have been no sand left, *in any river or on any shore*, unless the supply had been recruited by other larger pieces of rock being ground down into sand, which is precisely the origin we are claiming for all sand.

and the fractures fresh, the yet unhealed scar perhaps plainly visible in the cliff above. We should see also blocks having every gradation of form, from this newly broken angular fragment to smaller and smoother, well rounded boulders and pebbles, having every projecting angle ground off and all the surface worn as smooth as a billiard-ball. This has been effected by the frequent moving and rolling* of all these blocks one against the other on the pebble-beach or in the bed of the torrent, every roll removing some little corner, chipping off some little projection, each separated fragment being itself shortly smoothed and rolled into a pebble or shingle, and all the waste of this process being carried off by the moving water in the shape of sand.

We come then now to look upon, not only all sand as a waterworn material, but upon every pebble and every detached stone, of whatever shape and size, whether found in river, lake, or ocean, if it has at all a worn and rounded out-

* The power of water to move blocks of stone that *are in it* must not be measured by the power required to move them in air. Stone loses more than a third of its weight in water. Let any one standing up to his middle in water lift a large stone from the bottom, he will find that he can raise in the water a mass that, as soon as he attempts to lift it out of the water, is quite beyond his strength. A block of stone weighing 100 lbs. in the air will often only weigh 60 lbs. in the water.

line, as having probably acquired that outline by the action of moving water, and as having been probably transported by that action from its parent site to the place where we now find it. But, as in the case of the sand, so in that of the pebbles and boulders—if all those found in rivers or on shores have been rounded by the action of moving water, it is, *à priori*, highly probable that all pebbles and boulders and round stones whatever, however high and dry they may now be on plains or hills or mountain-slopes, are in fact but water-worn fragments of older rock.

There are two mineral substances which enter more largely into the structure of all rocks than any other: these are Silica and Alumina. The most common form of silica is quartz, which is almost entirely pure silica. Rock-crystal is a common name for quartz in its crystalline form; in this state it is quite transparent; it however is often found in veins in the hard rocks as an opaque milk-white stone, very hard and brittle. When quartz is coloured dull white or brown by the slight admixture of other substances, it is called flint. All non-crystalline quartz, and most rocks that are made of it, when broken by the hammer or in any other way, commonly split into squarish or cubical lumps, which, when acted on by moving water, soon get their corners

rounded off so as to be easily rolled or moved, either as large pebbles or as small round grains. It is partly for this reason, and partly on account of their superior hardness and unyieldingness to chemical or mechanical force, that the great majority of all pebbles and sand consist of quartz. If we re-examine with a lens our handful of sea-sand, we should find all the little glassy-looking or semi-transparent grains, and most of the opake ones, to be made of quartz, mingled perhaps with grains of a few other substances, and, in the case of sea-sand, with grains of broken shell or coral, or other sea creatures. From this connection between quartz and sand, it comes that all sandy or *arenaceous* rocks are more or less purely quartzose.

Alumina is a substance that does not commonly occur in any pure form, as silica does in quartz, but which enters into the composition of many minerals, giving them the property of forming clay. Every one knows what clay is in its commoner form. Its varieties depend on the varying proportion of the mixture of alumina with silica and other substances. Pure alumina however would not make clay, as pure silica does quartz. Some of the hardest gems, such as sapphire, corundum, and emery, are nearly pure alumina. When however a rock formed of such minerals as feldspar or horn-

blende, containing a certain proportion of alumina, becomes rotten or decomposed, the decomposed part forms what we call clay. Such rocks, or rather the rocks formed of such decomposed matter, are called *argillaceous* or clayey rocks. Now if a block of any argillaceous rock, or of any rock containing the constituents of clay, be acted on by moving water in the way we have already described, it is evident that the ultimate effect of the wearing and grinding of its particles will be to produce clay or mud rather than sand.

As however most rocks contain several minerals, some of which are more silicious, some more aluminous, the ultimate effect of their *degradation*, as it is called, by water, will probably be that one part is ground down into sand, and another triturated into mud. It will often happen also, from the mixture of the two substances, that the difference between mud and sand will depend rather on the minuteness of the subdivision of the particles than on their mineral composition, so that that which is now sand might be readily ground down into clay and mud, or that what is now mud formerly existed as sand, and before that as pebbles. Clay or mud therefore must have just the same origin and method of formation as sand or gravel.

We will now entreat the reader to let this fact (or if he

pleases for the present, this possibility) sink deeply into his mind :—

All detached pieces and fragments of stone or rock, whether they be boulders of many tons weight, or pebbles, or sand, or clay, or mud, have once formed portions of large, solid, originally formed masses of rock, and have all (with the exception of matters actually blown from the crater of a volcano) acquired their present form and condition through the action of running water.

There is not a shower of rain that falls, whether on the crowded street, the dusty road, the plains, the hills, or the mountain summits, that does not cause a multitude of rills and streams of muddy water to flow from higher to lower levels. The mud borne along by that water was once part of a solid rock. Even if it be but the waste of the bricks and tiles of our houses, this is still true; and it is equally true for every other case, except for those particles of it that may be the result of the decomposition of animal or vegetable matter. Even the gentlest rain that soaks silently into the most richly carpeted meadow of grass, contributes to the stock of water contained below ground, which here and there bursts forth in springs, carrying momentarily some grain of mineral matter to the brook, the river, and the

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THE LITTLE BOAT ON THE LAKE, 1841.

ocean. Who has not seen the springs discoloured after heavy rain? Who has not watched in wet weather the swollen brook or the roaring mountain-torrent, with its thick, muddy, coffee-coloured water? Who does not know the flooded aspect of a river, with its dull, yellow, turbid eddies, so different from the limpid stream that commonly flows between its banks? Whoever has seen these things, has seen one of the multitudinous actions of nature which are for ever and everywhere in operation, performing slowly, and in the lapse of ages, mighty works by means apparently inadequate and at first sight perhaps not especially adapted to the purpose.

There are however other agencies at work, agencies acting with greater local power than mere rain, in wearing away solid rocks and transporting the waste to other localities. We have alluded to the action of brooks and rivers; but if we were to trace them more minutely and in detail, and follow them up to where they acquire a swifter stream, or where rapids and cataracts occur in them, we should estimate still more highly their destructive power on solid rock. Rivers are in fact great natural saws or planes, for ever grooving furrows in the land. Let any one look at the bed of a mountain torrent, where it has cut a deep ravine

through hard rock, and he will see the amount of its force perpetually acting through uncounted ages. As a well-known example let him take the Falls of Niagara, as detailed in Sir C. Lyell's 'Principles of Geology,' and he will see somewhat of the nature of river action in deepening its own bed through the destruction and transportation of the rock composing it.

Equally good examples on a smaller scale however are to be met with almost everywhere. On the north side of Newfoundland I once met with one of these, admitting of good illustration, in the River Exploits, which runs out of the desert interior to the head of Exploits Bay. About twenty miles above the mouth, the river falls over a ledge of hard, dark red gritstone and compact "slate rock," a height of about thirty or forty feet, the fall being divided into two by a small rocky islet covered with the same wood of stunted fir-trees that stretches all over the country*. Above the falls the river is one hundred and fifty yards wide, very shallow, its bed composed entirely of huge boulders. Below the falls it is contracted to a channel of fifty, or in some places only twenty-five yards in width, and it runs in a narrow precipitous ravine (full of ledges and ridges of bare

* See Frontispiece.

hard rocks striking right across it) for at least a mile, when it issues out into a wider valley in a lower piece of country. At the mouth of this ravine stands a pinnacle of rock called Buchan's Island, just in the centre of the river, formed of the same rock, and exactly of the same height, as the banks of the ravine on either side*. This pinnaele of rock evidently marks the position where the falls once were, at which time it formed just such an island, dividing the falls into two, as we see in the existing falls at the present day. The intermediate part of the ravine, a mile long, and on an average fifty yards wide and forty feet deep has clearly been excavated by the grooving action of the river on rocks of the hardest and most intractable character.

On mountain-tops, or in high latitudes even on lower ground, frost is another great agent of degradation. Any one who ascends the mountains of our own islands for the first time, will often be surprised at the multitude of angular fragments and fallen blocks he sees scattered over their summits or piled at the foot of their preeipices. Of these many, if not most, have been detached by the action of frost causing the water contained in the joints and crevices to expand and rend them asunder, just as in a cold winter's

* See Plate II.

night the jugs and water-bottles are apt to be burst by the frost in our bed-rooms.

If we were to visit mountains such as the Alps, where glaciers are formed, we should see still another effect of frost. A glacier is in fact a stream of ice slowly descending the mountain-side. In its slow but mighty and irresistible progress, it exerts an enormous force in grinding and grooving the rocks on which it rests, tearing off many of the projecting blocks it meets with, and, by undermining the cliffs at its sides, causing blocks to fall upon its surface. These blocks it constantly carries forward, till it comes to the boundary, where it melts away, when it of course deposits them. They there form a huge mound or ridge of broken fragments, called in the Alps a "Moraine."

Similarly in all those countries where ice forms periodically in large quantity, either on the rivers or on the sea-shores, it both rends asunder and grinds up whatever rock it comes in contact with, but more especially in these cases does it aid in carrying off to distant localities blocks already detached. It encases these in its own mass, freezes them in, and when it is itself floated off, bears them along with it, transporting them perhaps many miles, or, in the case of icebergs, even many hundred miles from the place where it

found them, and, on melting, drops them at the bottom of the sea.

Of all agencies, however, the most efficient in the destruction and degradation of rock, because it is both locally powerful and very widely diffused, is the action of the sea-breakers. In all climes, in all latitudes, along all shores of all seas and oceans, this action is ceaselessly at work, day and night, summer and winter, gently and imperceptibly even in calms, furiously and vigorously in storms, gradually but steadily in moderate weather, wave after wave is launched from the sea against the land, eating and tearing it away.

No one can have visited the soft cliffy shores of the east and south of England without having been almost an eye-witness of this action. It is nowhere perhaps better displayed than on the coast of Yorkshire, near Scarborough. I well remember many years ago being struck, when attempting to walk under the cliffs from Scarborough to Filey Bay, with the enormous slices or square pilasters of cliff, that, having been undermined by the action of the breakers at high water, had fallen forwards headlong into the sea, the empty space they had once filled in the precipice above showing its still freshly exposed and jagged surface, gaping from the wound.

In Lyell's 'Principles of Geology' the reader will find many most interesting details of the existence of land, and towns, and villages, along the east coast of England, the sites of which are now even miles beneath the sea.

But if we leave these soft and easily destroyed rocks, and come to the hard and rugged promontories of the West of England, of Wales, of Ireland, or of Scotland, we still have evidently signs of the same action, though here it has been of so slow progress, that human records fail to tell us of its steps. Let any one however traverse any of these coasts when a wild western gale is stirring up the Atlantic from afar off, heaving its waters into huge mountainous ridges, crested with foaming breakers, and bringing them up rank after rank to fall madly on the land, dashing the white spray high over cliff and headland, and making even the solid rocks on which he stands to shake and quiver with the blows. He will then have no difficulty in understanding the reason of the broken and indented coast, of the jagged cliffs, of the pinnacles of rock jutting out here and there, and of the projecting lines of reef showing often like black knobs far out among the foam of the breakers. He will see that wherever there is a bay or indentation, the rock was originally softer, or the land was lower, than ordinary ; wher-

ever there is a promontory the rock was harder, or was *so placed* as to be able better to withstand the waves ; wherever there is a projecting reef or line of rocky islets stretching out to the sea, there the rock was of the hardest and most unyielding character. What is this but to say that the sea has worn all these indentations, has eaten away the sides of the promontory, has destroyed the land that once covered and protected the reef, or that once connected the line of islets with the main, and that it would have destroyed them also, had they not in some degree resisted its power, standing up as yet to mark the amount of destruction that has taken place around them, but ultimately themselves to yield before their unrelenting foe, and disappear beneath the waves like their brethren before them ?

The accompanying sketch of Baginbun Head, county Wexford, in Ireland, will give an idea of such a coast as is here spoken of, where, in spite of the rocks being of the hardest and most unyielding character, they have evidently been worn into ruins by the action of the sea. (Plate III.)

The sketch of Doonsorske Rath, Carrigadda Bay, county Cork, to which my attention was drawn by my colleague, Mr. G. V. Dunoyer, is one that gives a good illustration of the union of historie, or at all events archæological,

testimony with geological evidence of the erosive action of the sea. (Plate IV.)

The ridge on which the figure stands is part of the inner wall of an old camp with a double ditch outside. It is clearly part of a considerable work that once defended some small headland or other piece of ground from attacks from the land side. The tradition among the inhabitants is that all such camps are of Danish origin; but whatever may be its exact date, it is clear that the ground it was intended to defend at the time of its erection is now almost entirely destroyed by the action of the sea-breakers undermining the cliffs and sweeping away the fallen fragments. The rock is a hard gritstone, with bands of close compact slate, calculated, one would think, to resist the wear and tear of almost uncounted ages. Its destruction however has been facilitated by the position of the beds, which strike outwards or project into the sea, so that the waves attack their edges and by wearing them away undermine the cliff above. Had the beds sloped outwards from the land towards the sea, the breakers would have had only a smooth surface to act on, and might have washed up and down it as if it were a sea-wall, and thus required a longer time for the destruction of an equal amount of rock. Even in this case however

the delay might have been compensated for by greater portions of the cliff above sliding forward at once into the sea along the plane of the beds when slightly loosened, than can take place now by the crumbling process consequent on the beds striking or projecting from the land to the sea.

But this destructive action of the sea-breakers is neither confined to northern latitudes nor to stormy times. Within the tropics, under the gentle but perpetual pressure of the trade-winds, always acting in one direction, the swell of the sea, although but faintly perceptible in the open ocean, yet acquires a force that causes a terrific surf on all shores exposed to its influence. The sunny islands of Madeira and Teneriffe are constantly environed with a surf such as we only see on our most exposed western headlands, rendering landing almost impossible except in one or two comparatively sheltered spots. St. Helena, Ascension, Tristan d'Acunha, and all oceanic islands are similarly difficult of access, and often, like St. Helena, environed with the most lofty, perpendicular, and inaccessible cliffs, attesting the power of the erosive action of the sea.

In the South Atlantic Ocean there occur, in addition to the ordinary storms, great periodical agitations of the sea, producing enormous waves called "rollers." These are

probably caused by distant gales of wind ; but they occur occasionally—especially about the three islands just mentioned—without any warning, in ordinary calm weather, setting in sometimes quite suddenly in enormous waves, rolling and breaking with the utmost fury on the land. When landing in St. Helena in 1846, I was shown the wreck and ruin of a sort of quay and the buildings upon it, caused by a recent exhibition of these rollers. A schooner had been torn from her anchors, and lifted high and dry upon the little pebble-beach above high-water mark ; a crow's-nest battery was pointed out to me on the perpendicular face of the cliff, 120 feet above high-water mark, into which the spray broke on that occasion. It is probable that, if a heavy train of artillery were to surround the entire island, and batter away at the cliffs for some hours, it would not effect a greater destruction and wearing away of the rock than takes place during the occurrence of some of these rollers.

On all the coasts of the Indian and Pacific Oceans, especially those tropical coasts open to the east, the surf is never ceasing. That of Madras is an example well known to every one. Even on the calmest summer evenings, when standing in the outskirts of the city of Sydney in New South Wales, the roar of the surf on the cliffs outside the

harbour can always be distinctly heard, though at a distance of seven miles. A similar surf perpetually rages along the whole eastern coast of Australia, either on the land or on the coral-reefs outside of it, which I have elsewhere attempted to describe. (*Voyage of the Fly*, vol. i.)

We have no space however to accumulate particular examples ; and enough has probably been said to impress upon the reader's mind that the sea along every coast in the world is daily and hourly and momentarily exerting an erosive or wearing action upon all rock or earthy matter with which its breakers come in contact, that action being occasionally stimulated into intense power by storms and other paroxysmal influences.

Now arises another question—what becomes of all this waste of earthy matter ? what becomes of all the mud carried down into the brooks,—of all the mud, sand, clay, or gravel swept down the rivers,—of all the blocks, boulders, shingle, sand, or mud, torn from the cliffs by the seas, ground up upon the beaches, and swept away by tides or currents ? To answer this question we will take another chapter.

CHAPTER II.

THAT SOME ROCKS ARE FORMED UNDER WATER, AND ARE
THEREFORE CALLED AQUEOUS ROCKS.

WE commenced by asking the reader if he knew what sand was ; we will now ask him to examine a piece of sandstone. The very name at once teaches us what sandstone *must* be—it is a stone made up of grains of sand. If the reader will examine any piece of sandstone or gritstone, taking a lens if it be fine-grained, he will see that it is made up of small rounded grains, exactly like those of sea or river sand, consisting for the most part, if it be white sandstone, of little rounded fragments of transparent or semi-transparent rock (almost invariably quartz) ; if it be a dark brown or red or other coloured sandstone, of similar grains of the same mineral, stained or coated with some other substance. If we take a piece of sandstone and pound it with a hammer,

we reduce it to sand. Now we have already seen that all sand was composed of the small fragments of pre-existing rock, *rounded by the action of moving water*. We are therefore obliged to conclude that all sandstone is composed of fragments of pre-existing rock, rounded by *the action of moving water, deposited at the bottom of that water, and subsequently compacted together into stone or rock*.

If we take a piece of any originally formed rock, such as granite for instance, and pound it down with a hammer, and examine with a lens the particles thus gained, we should see a sensible difference between them and the grains obtained from pounded sandstone. The particles derived from granite, even those consisting of quartz, would have all their angles clear and sharp; there would be no marks of wearing or grinding on them (except such as may have been caused by the hammer); they would evidently not be water-worn, like the grains of sand.

We are here on the traces of a very remarkable difference in the nature and constitution of all the rocks comprising the crust of the globe, so far as they are accessible to human research,—a difference that lies at the very basis of all geological science, as the reader will ultimately discover. For the present however we shall be content with the fact that

all sandstone is made of sand, and that sand is the water-worn fragments of pre-existing rock.

Now there is another kind of rock or stone very frequently associated with sandstone, commonly known by the name of "pudding-stone," and called by geologists "conglomerate." This usually consists of a basis or matrix of sandstone, in which are imbedded large or small pebbles, or fragments of stone more or less completely rounded, and varying in size from nuts up to quartern loaves. This rock is so evidently made up of the rounded fragments of other rocks, that it is needless to insist on the fact. As indeed the pebbles in conglomerate are often sufficiently large to retain the characters of their parent mass in a recognizable form, we are sometimes able to trace them home, and to say, not only that they are water-worn fragments of pre-existing rock, but to declare what that rock was, and where it was situated.

Not unfrequently we see one sort of rock reposing "*in situ*," as it is called—that is, in its native site,—and another resting upon it, and containing rounded fragments or pebbles of it. In this case it is evident that we have before us an old sea-beach, or other place where moving water acted on the lower rock, breaking off fragments of it, rounding

them into pebbles, and grinding them into sand, and that part of those water-worn materials, but little removed from their parent site, have been re-compacted together, to form the upper rock.

If now, having gained these ideas of the nature and origin of sandstone, we were to trace it in the other direction, and instead of following it up to pudding-stone or conglomerate, were to examine successive specimens of a gradually finer grain and smoother texture, we should see that this fineness was either the consequence of an alteration in the nature of the material, and the consequent shape of the particles, or of their size. The grains may become flakes, and get so small as to be invisible to the naked eye, still they are not the less water-worn particles. In this way we can sometimes trace sandstone becoming finer and finer, till we arrive at a rock for which we have no very commonly received or accurate distinctive name,—a flinty or silicious rock, with a perfectly smooth compact texture, a conchoidal or shell-like fracture, without anything we could call “a grain.”*

* A rock of this kind, when met with in the coal-measures of South Staffordshire, is there called “a peldon;” and as I know of no other name to give it, I venture to propose that designation for the acceptance of my brother geologists.

When however the rock ceases to be composed exclusively or principally of silicious or arenaceous particles, and is largely mingled with those of aluminous or argillaceous matter, it then passes from a sandstone into one of the various forms of clay, such as marl, clunch, shale, claystone, mudstone, and clay-slate.

We have already, in the last chapter, spoken of clay as the waste of pre-existing rock containing aluminous or argillaceous matter.

Marl is properly clay containing a small admixture of lime, binding it together into a loose, crumbling kind of stone.

Loam is clay mingled with fine sand, so that it no longer easily adheres together.

Clunch is clay compacted into a soft stone, easily reducible back into clay.

Claystone and *mudstone* are simply clay and mud hardened into stone.

Clay-slate we will describe hereafter.

Shale is a fissile, indurated clay, that splits naturally into thin plates or laminae.

We are now able to answer the question with which the last chapter closed, with a very high degree of probability, to say the least of it. If all the rocks now described are

G. V. DuNoyer, del.

Holme and Watson lith.

BAGINBUN HEAD, CO. WEXFORD, IRELAND.

thus made up of water-worn materials deposited in the bottom of the water, it becomes tolerably certain that all the waste of rock which is caused by the moving waters of brooks, rivers, lakes, and seas, is eventually deposited in their deeper and stiller portions, where it is gradually formed into these kinds of rock. We must feel pretty sure also that *in all our present lakes and seas, without exception*, there is constantly taking place, *in one part or other*, a deposition of such materials, which, when accumulated in any quantity, bed over bed, must be, by the mere weight and pressure of the superincumbent portions, compacted together into tolerably firm stone or rock.

As we saw reason to suppose, in the case of all rounded stones, boulders, pebbles, gravel, sand, or mud, wherever they were found, whether on the actual beaches or far inland upon high ground, that they had acquired their present form and disposition from the action of moving water, so we are compelled to conclude that all rock made of these materials, whether conglomerate, sandstone, shale, marl, or clay, has been formed under water by the deposition of these materials in the bed of that water, however far they may now be removed from any large space of water, either in distance or height.

If we had any doubt on this point, we should not be able to continue our examination of such rocks very long without having those doubts removed by discovering in them the remains of animals and plants that had lived in or had been carried into the waters.

We should find in some sandstones huge stems of trees, more or less completely converted into stone, in some cases changed into the purest flint, in others converted into lignite or into coal. In some sandstones, and in many shales, we should find the leaves and stems of plants, with all their delicate tracery exquisitely preserved. In many rocks, whether arenaceous or argillaceous, we should find either the entire bodies or the “casts*” of shells, crabs, corallines, seaweeds, and other aquatic beings, often occurring in regular beds, and under such circumstances as prove them to have lived and died in the place we now find them, when that place was covered with the waters of lakes and seas. We find also the skeletons of fish, reptiles, birds, and quadrupeds,—bones either of animals that lived in the waters, or of carcasses that have been carried into them from the land by the action of rivers.

* By a cast we mean the form of a fossil moulded in the rock, the mould remaining after the fossil has rotted away.

If we required any other evidence, then, than the mere structure of the rock, to prove that all the rocks of which we have been speaking, such as sandstone and conglomerate, shale, slate, and the various forms of clay, were formed by the slow and gradual accumulation of earthy matters under water, we should have in these facts abundant proof of the position.

Now, to rocks formed by such agency we may rightly assign the term “mechanically formed rocks:” they have been produced by the simple mechanism of moving water, transporting earthy matter from one position to another.

There is however another set of rocks, which we may with equal reason call “chemically formed rocks.” Of these limestone is the principal and most abundant; but there are some others, such as gypsum and rock-salt.

Almost every one must have heard of “petrifying wells and springs,”—places where birds’-nests, wigs, sticks, and other articles, being placed in the water, become in the course of a few weeks incrustated over with stone, which, when tested, is found to be limestone, or what the chemists call Carbonate of Lime.

The waters having this property are often quite pure-looking and transparent, holding this mineral substance in

perfect solution, as if it were melted salt or sugar,—not in mechanical suspension, or in the state of mud or sand. The chemist indeed tells us that perfectly pure water,—that is, water having no mineral substances whatever dissolved in it,—is a very great rarity on the face of the earth, much rarer than are now-a-days the black swans the poet made such a fuss about.

We can easily understand that water, which under one set of circumstances can dissolve mineral substances, will under another set of circumstances precipitate them or deposit them at its bottom.

Without attempting to puzzle ourselves with any of the recondite mysteries of chemistry, we may recollect that both salt and lime are nothing more than the oxides or rusts of metals called sodium and calcium. Just as iron-rust is an oxide of iron, so is lime simply the rust of calcium; while salt is the rust of sodium, or soda, combined with an acid called hydrochloric or muriatic acid, or spirit of salt. Soda combines with muriatic acid, to make salt; lime combines with carbonic acid, to make carbonate of lime, or chalk and limestone, and with sulphuric acid, to make sulphate of lime, or gypsum.

Now, simple carbonate of lime is only sparingly soluble

in water; but if to the lime a double dose of carbonic acid be added, or it become what chemists call a bicarbonate, it is soluble in water to a much greater extent.

If therefore the waters of a brook or spring contain any quantity of carbonic acid mingled with them, and they come in contact with any lime or limestone in their passage, they will dissolve a portion of it and hold it in solution, till, either from the evaporation of the water or the abstraction of some of the carbonic acid from some cause or other, the carbonate of lime becomes solid again, and incrusts whatever happens to be nearest at hand. Hence, the phenomena of petrifying springs, as also of the stalactites and stalagmites so often found in limestone caverns.

Stalactites are the result of water holding limestone in solution dripping from the roof of a cavern, each drop depositing a portion of the limestone in its passage, forming thus long pendent icicles of stone (if we may call them so), assuming often the strangest, most fantastic, and most beautiful forms. The remainder of the water, falling on the floor of the cavern, forms there a crust, which is called the stalagmite. When a drop of water falls frequently and through a long period on the same spot, the gradually deposited carbonate of lime forms a pinnacle slowly

growing towards the roof. Sometimes the pendant from the roof is continued till it meets the pinnacle rising from below, and the two unite to form a pillar; sometimes a long crack in the roof has a regular stream of drops falling from it, which then unite to form a connected sheet, or curtain, of semi-transparent limestone*. In Plate V. examples of all these forms will be seen, and on the right hand a succession of thin curtains of stalactite, the result of water oozing rapidly through the joints of the roof.

In some countries, springs containing limestone in solution deposit it in great quantities on the hill-side, where they break forth, forming huge sheets and blocks of rock, sometimes light and porous, when it is called *Calcareous Tufa*; sometimes hard, firm stone, when it is called *Travertine*. The term *Travertine* is derived from the fact of this stone occurring largely on the banks of the *Tiber*, where it has been long used as a building stone, and where it forms precipices even hundreds of feet in height†. On the small

* The sketch is taken from the celebrated caverns at Mitchell's Town, county Cork. It is however a composition, not an actual sketch of any one spot; the different kinds of stalactite and stalagmite found in different caverns are here grouped together, in order to get them into one sketch.

† The reader will find many interesting details as to the Italian travertines in Sir C. Lyell's '*Principles of Geology*.'

scale, calcareous tufa and travertine are constantly to be met with in our own country, on the banks of rivers and brooks where there is any calcareous (that is, limy) matter in the neighbourhood; and sometimes they occur in very considerable mass, as at Southstone Rock, on the river Teme, and on the eastern slope of a little valley south of Ballycastle, county Mayo, in Ireland.

Now, as in all these cases we see solid calcareous rock deposited from water under our very eyes, and can trace the method of its formation, we are naturally the more disposed to believe that similar rocks may be formed beneath the waters of our present seas and lakes, or that the calcareous rocks which enter so largely into the composition of all the existing lands have been so formed in former times, when those lands must have been covered by water.

If however our belief of the aqueous origin of arenaceous and argillaceous rocks was strengthened and confirmed by finding them so full of the remains of animals or plants that had inhabited the water, or whose remains had been swept into it, much more will this be the case as regards the calcareous rocks.

All calcareous rocks abound in fossils; whether they be chalk, limestone, or marble, they are for the most part full

of shells, corals, starfishes, sea-urehins, crustacea (such things as crabs and lobsters), teeth and bones and scales of fish, bones of sea reptiles, etc. In some instances, whole mountain masses are entirely made up of the fragments of sea-creatures, and sometimes of only one kind of sea-creature : such are the erinoidal* marbles, often used for chimney-pieces.

The ornamental markings of many marbles, indeed, are derived from the forms of the fossils imbedded in them ; and they are sometimes present even when least suspected. If, for instance, the reader will take a lump of common chalk, and break it down into powder, and wash it frequently in water, pouring off the milk-white muddy water of each washing, he will almost invariably have left, at the bottom of the saucer, a quantity of minute shells and microscopic marine animals.

It would be impossible for any one to attentively examine any limestone country, and see the way in which the shells and other fossils, often of the most delicate, fragile, and beau-

* So called because they are almost entirely composed of the fragments of the stems of erinoidal animals,—the Sea-Lilies, animals resembling a starfish, growing on a stem, with the fingers split up into a multitude of jointed filaments.

tiful structure, lie in bed over bed, and layer over layer, with the utmost order and regularity, over large areas, without being convinced that the whole mass of rock had been gradually accumulated at the bottom of the sea. We have moreover reason to believe that some limestones are composed of the waste of shells and corals, even in the parts where recognizable portions of them are not now discernible. Round all the northern and eastern coasts of Australia, the lead, when bottom was struck in the open sea, generally brought up a light green mud, wholly calcareous and soluble in dilute muriatic acid, the result of the wear and tear of the coral-reefs abounding in those seas. Limestones formed in this way must be considered as of mechanical, not of chemical origin,—the detritus of the hard parts of animals that had separated the lime held in solution by the sea. Even when derived mechanically from organic beings however, they often have an internal chemically formed structure.

If, now, we call all rocks formed under water Aqueous rocks, and methodize the results we have arrived at, we can tabulate them in the following form: first premising that as all aqueous rocks were formed by the gradual accumulation of bed above bed, or “stratum” over “stratum,” they may also be distinctly called Stratified rocks.

AQUEOUS OR STRATIFIED ROCKS.

Mechanically formed.	{	Arenaceous.	{	Sand, Gravel, Conglomerate or Pudding- stone, Breccia, Sandstone, Gritstone, Peldon.
		Argillaceous.		Mud, Clay, Marl, Clunch, Shale, Clay- stone, Mudstone, Clay-slate.
Chemically formed.	{	Calcareous.	Chalk, Limestone, Marble,	
		Gypsum or Plaster of Paris.		
		Rock Salt.		

That gypsum and rock-salt are aqueous rocks is shown by the way they are interstratified with the other aqueous rocks, of which however they form a very small proportion. Coal must likewise come under this head ; but there are some points about the method of its formation, which render it more convenient to reserve its discussion for a future occasion.

CHAPTER III.

THE STRUCTURE AND MODE OF OCCURRENCE OF
AQUEOUS ROCKS.

WE will now describe the structure of the Aqueous Rocks. To understand this matter properly, it is absolutely necessary that the reader should make his own observations in the field, and attentively examine all quarries, pits, cuttings, and cliffs that he can meet with; we can only hope to be useful in calling his attention to what he will there observe.

ARENACEOUS ROCKS.

If he go into a sand- or gravel-pit, he may sometimes find the whole mass of material, especially if it be mingled with much clay, confusedly heaped and piled together, without any order or arrangement. This however will be quite the exception to the rule. Even if the gravel consist en-

tirely of large pebbles, he will generally perceive that it has more or less of a stratified character. If the pebbles are flat or oval, they lie with their flatter and broader surfaces mostly in one direction, as if each pebble or each layer of pebbles had had time to assume its natural position of rest (that position in which it would fall and lie if rolled now along a road) before it was covered by the others lying upon it. There may often be seen a layer of large pebbles alternating with a layer of smaller size, the layers being a few inches or several feet in thickness*. The whole mass will often be mingled with, and as it were bedded in, sand; and beds of sand, either alone or with a few pebbles scattered about it, will often occur between or among the layers of pebbles.

If the pit be a sand-pit, it will most commonly have a still more distinctly stratified character, the strata or layers consisting of sand varying in colour or in fineness of grain, or in mineral composition.

These layers, in both sand and gravel, are apt to be irre-

* See Plate VI., where the layers are heaped up all in one direction, so as to give a very regularly stratified appearance to the whole. This is rather the exception than the rule: gravel is generally accumulated in the way shown in Plate VII.

gular, both in position and extent; they are rarely strictly parallel to each other, and they frequently increase or diminish in thickness, often ending pretty suddenly, by thinning out, as it is called, altogether.

If a layer of clay occur in the mass, as sometimes happens, it will probably be much more even and regular, and extend further, than any similar layer of sand and gravel.

The irregularity of the layers in sand and gravel, and the frequent alternation and mixture of the two sorts of materials, shows that the water in which they were deposited was affected by currents varying frequently in strength and rapidity, or in direction, or in both. These currents were sometimes able to roll along large pebbles, sometimes could only move fine sand; sometimes they tended to carry forward and heap up the material in one direction, sometimes in another; or sometimes the water moved from a direction in which sand only was to be procured, sometimes came from a place whence it brought pebbles also. In either case the currents must in one part have had strength enough to roll the materials onwards, while in other parts that strength failed, and the pebbles or sand sank and rested at the bottom.

Our supposed layer of clay, and its greater evenness and extent, would be an evidence of comparative tranquillity.

Very fine mud remains suspended in water for a long time before it sinks to the bottom, and thus a very slight current is sufficient to diffuse the mere muddy water over a large space, and it must become almost perfectly still before the mud finally sinks and rests upon the bottom.

It is scarcely possible to describe the general aspect of sandstone and conglomerate in any other terms than those used for sand and gravel; the only difference being that in the one case the materials are still loose and incoherent, in the other they adhere more or less firmly together.

When the fragments of a conglomerate are very angular, it is called a Breccia. This angularity shows that they have been little waterworn, and probably travelled but a short distance. When the fragments are well rounded into pebbles, they have sometimes been washed great distances from their parent sites. This removal perhaps did not take place all at once, or continuously, as the pebbles may have rested upon many beaches, or been rolled frequently, and even entered into the composition of several different rocks, before they were finally covered up and buried in the place where we now find them.

Beds of conglomerate are commonly very irregular in thickness and extent; they are almost invariably interstra-

tified with sandstone, each kind ending sometimes suddenly in the mass of the other, as in the accompanying sketch. (Plate VII.) They vary likewise greatly in hardness: sometimes a slight blow is sufficient to detach the pebbles from the matrix, or they can be pushed out almost by the finger; sometimes it is almost impossible to detach them even with the hammer, a blow of which makes a clean crack across the whole mass, the pebbles, even those consisting of the hardest flint, splitting equally with the rock in which they are imbedded.

Sandstones vary in hardness, equally with conglomerates, from a soft friable stone that can be cut with a knife or scratched with the nail, to a stone so hard as to be with difficulty cut with a chisel or broken with a hammer. It is not always easy to say why the grains of which a hard sandstone is composed adhere so firmly together. Sometimes they are bound together by the infiltration of some other mineral matter, as lime or iron, but sometimes it appears as if simple pressure had been the cause of their cohesion*. Very many sandstones have, mingled with the

* I may remind the reader that small bricks for tessellated pavement, and hard black-lead pencils, are now formed simply by the powder of their materials being subject to great pressure, with simultaneous exhaustion of the air.

round silicious grains, small spangles or flakes of mica; these are sometimes so large and so abundant as to communicate a distinctly fissile structure to the mass, making it split into thin laminæ, almost like shale. When the mica is abundant, this rock is called micaceous sandstone. There is no very clear distinction to be drawn between sandstone and gritstone, except that a gritstone, whether coarse or fine grained, is generally composed of "sharper" (more purely silicious) materials than a sandstone.

One character more or less common to all the mechanically formed rocks, but which is more conspicuous in the sandstones than any other, is that ordinarily known by the term "false bedding," but for which the better term perhaps is "oblique lamination."

By the planes of bedding or stratification we ought always to understand the upper and lower surfaces of a bed or stratum, whether it be a few inches or many feet or even yards in thickness. All the minor layers within the bed require a distinctive appellation, for which the term laminæ and lamination, though not unexceptionable, may yet be accepted. This lamination may be all parallel to the planes of stratification, or it may be oblique to them; moreover the laminæ may not all be parallel to each other, but lie at

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various angles and incline in various directions. By a bed, or stratum, there should be understood a series of layers or a succession of deposits of earthy matter so continuously formed that the whole adhere more or less firmly together. When a pause in the deposition took place, and a consequent distinct line of separation between that mass and the one above it, that line would form the top of one bed and the bottom of another. That is the stratification. As to the lamination, or the continuously deposited layers, the materials might either fall regularly and equably from above, in which case they would all be horizontal and parallel, or they might be brought in laterally by currents of water, and irregularly, so that a greater accumulation or bank was formed now in one place, now in another, and the material deposited on the slopes of these banks. Sometimes the current might be regular and steady, and the material abundant and falling rapidly to the bottom; in this case a bank would quickly be formed on the side the current came from, and all the successive additions would be deposited on the slope of this bank. This action might be extended over a considerable space, and so continuously that all the materials would adhere together on the consolidation of the mass, which would then form a large bed, having perhaps the top and bottom

horizontal or nearly so, while the layers of it were regularly inclined at a considerable angle in one direction.

Again, it would often happen, in water having rapid currents, that a bank of earthy matter, after being deposited, might by a shift or alteration of the current have more or less of its upper surface cut away,—planed, as it were, smooth off,—and on this new surface another bed might be deposited, having its layers inclined in an entirely different direction to those of the lower bed. This action might be again and again repeated with every imaginable variety, producing the varied structures we should often find prevailing in the arenaceous rocks. (See Plate VIII.)

Another structure, often conspicuous in fine-grained sandstones, is that commonly called “ripple mark.” Either in quarries or natural cliffs, wherever the upper surface of a bed is exposed, it is often found to be not smooth or flat, but waved in small undulations, exactly like those so often seen on a sandy shore. Now a good deal of misconstruction has, I think, arisen as to the origin of these small undulations or ripples in the sand, leading sometimes to a possibility of grave error in geological reasoning. People standing on the beach and observing the gentle rippling motion of the waves, and a very similar form in the sand beneath

them, have not perhaps unnaturally jumped to the conclusion that the one was the cause of the other, that the ripple of the surface of the water had somehow imprinted its form on the sand at the bottom. Now really one is not the *cause* of the other, but they are both caused by the same action, and each is as much a ripple as the other. The wave-like form in the sand is not a *ripple mark*, but a *ripple*; if it is the mark of anything it is a "current mark," and as such I have always preferred to speak of it. Just as a current in the air produces a ripple in the surface of the water below it, so a current in the water produces a ripple in the sand below it. It makes no difference indeed whether the sand be acted upon by air or water. Wherever the circumstances are favourable, wind will cause a ripple (or current-mark) on the surface of blown sand, as I observed frequently under very favourable circumstances at Sandy Cape in Australia, and as has been observed by Sir Charles Lyell near Calais. (Lyell's Elements, p. 20, 4th edition.) In each case the moving fluid propels the grains of sand forward, piling them up into ridges, which are perpetually advancing by the rolling of particles over the crest of each ridge into the hollow beyond, where they are for a time sheltered from the current, but soon buried under the advancing ridge, to be again torn

up and rolled onward perhaps as their site becomes exposed to the force of the stream.

The ripple or "current mark" on the surface of a bed therefore is no trustworthy guide as to the depth at which the bed was formed, as has sometimes been supposed, for as the water is rippled by the wind or current of air at the bottom of the atmosphere, so may mud or sand be rippled at the bottom of the sea by the current of the water, *whatever be its depth*, provided the force of that current be sufficient to overcome the pressure of its weight to the necessary extent, and gently propel forward the sand or silt that lies below it.

When sandstones are very thin-bedded, or the beds are easily split along the lines of lamination, they are called flagstones. Flagstones however are not exclusively arenaceous, but may be argillaceous or even calcareous.

ARGILLACEOUS ROCKS.

In a stratum of common clay or brick earth, there is commonly but little appearance of lamination. The whole bed of clay, whatever be its thickness, is ordinarily one connected mass of matter, whether it be red, blue, grey, or white, with no divisional planes, nor with any variation in

character in its different parts, showing anything resembling structure. When this is the case, it shows that the water from which it was deposited was kept continually full, for a certain space of time, of a fine argillaceous mud, that has continually settled down as a sediment to the bottom of it over the space where we now find the clay.

Marl we have already spoken of, as clay containing a small portion of carbonate of lime, though many beds often spoken of as marl, are really nothing but clay. True marl, when dry, becomes tolerably hard, and splits naturally into small cubical or dice-shaped pieces. In consequence of the lime contained in it, it would never make good bricks, as when baked it would crumble to pieces; but for the same reason it is often excellently adapted for agricultural purposes*.

Loam is, as before stated, clay mingled with sand, but without any admixture of lime.

Clunch is a provincial term, signifying a slightly indurated clay.

Of the other varieties of argillaceous rocks, we must still reserve Clay Slate to a future chapter, but Shale is one which ought to be described now.

* The soil which reposes directly on soft sandstone interstratified with beds of marl, is commonly of the most fruitful character.

If the reader will examine a lump or slab of shale, he will find that it is an argillaceous material, or one which could be easily reduced into clay. It splits easily into thin plates, and on attentively examining these plates, or laminæ, it will be seen that each of them represents a separate act of deposition of sediment in water. Sometimes the laminæ are so exactly similar, that this is not at first sight obvious ; but very often they vary slightly in grain, colour, or mineral composition, one lamina being a little coarser or sandier than another, and so on. The different laminæ therefore, which are often not thicker than this paper, are evidently the result of the deposition of film after film of earthy matter at the bottom of water, each film having time to settle down and become sufficiently consolidated so as not to be amalgamated with those that afterwards fell upon it. This view is corroborated, if corroboration be necessary, by our often finding delicate leaves, or the thinner and finer portions of animals, such as insects' wings, cases of cyprides, or thin papyraceous shells, on the surface of each lamina in a bed of shale. In such thin laminæ of shale, we can, as in the leaves of a book, read the history of the production of all the aqueous rocks.

CALCAREOUS ROCKS.

The structure of the calcareous rocks is very various. Chalk is commonly a mass of exactly the same structure throughout,—a white, earthy, pulverulent carbonate of lime. It is often difficult, in a cliff or quarry, to distinguish its beds, the whole mass being divided by planes running in various directions into blocks of various sizes, with no lamination observable, and but little to mark the stratification from what is called the jointing of the rock.

Some ordinary limestone also is smooth, hard, and compact in its structure, in thick beds, with little or no marks of lamination (or the successive deposition of the minor layers of matter), although the stratification may be well marked, when a large quantity of the rock is viewed as a whole, by the regularity and parallelism of the division-planes of stratification.

Other limestones again are regularly laminated, or with the lines of successive deposition distinctly marked, and are sometimes also very thin-bedded, or flaggy,—splitting, that is, into thin coherent slabs of large dimensions, each slab being naturally and distinctly separated from the one above and below it.

As there are some limestones pulverulent, like chalk, and

some compact, so there are also others quite crystalline, a congeries of crystals of carbonate of lime, more or less perfectly formed, all interlaced, or growing as it were one out of another. This crystalline structure is sometimes coarse and large-grained, with the crystals very irregular; sometimes however it is fine-grained and regular, like the crystalline structure of loaf-sugar. It is hence called saccharine limestone or marble, and, when white and pure enough, statuary marble.

I have already spoken of limestones becoming ornamental marble on account of the varied markings produced by the fossils they contain. Other marbles acquire their ornamental character from the admixture of other mineral matter colouring the limestone with varied tints, or from the variations in their crystalline character producing pleasing forms and varieties of shade.

All limestone capable of polish would ordinarily come under the denomination of marble.

The reader may easily imagine, from the very nature of the formation of the aqueous rocks, that they are not all strictly such as have just been described, but that there are rocks that are of intermediate or mixed character.

First of all, among the mechanically formed rocks, there are some arenaceous or sandy rocks that are more or less argillaceous or clayey, and *vice versâ*. There are clayey sandstones, argillaceous gritstones,—there are shaly sandstones, as there are also sandy clays, marls, or shales. These rocks result either from the mingling of silt or detritus, derived from two distinct sources, or from the degradation of a rock having both arenaceous and argillaceous particles.

Secondly, the mechanical rocks may be mingled with materials chemically deposited, as the waters into which the mud or sand is brought down may themselves have held mineral matters in solution, that have impregnated the whole resulting deposit. On the other hand, water depositing or precipitating mineral matter from solution, may likewise have a slight admixture of sand or clay swept into it. In the first instance we may get calcareous or limy sandstones, gritstones, or conglomerates, or calcareous clay, shales, or slates; in the second we may have arenaceous or argillaceous limestones.

In this way also we may get gypsum or rock-salt mingled with mechanically formed rock. In practice we find those two minerals almost invariably associated with some form of clay, generally with marl, and far more abundantly with

red marl than with any other rock,—a fact of which I do not remember to have heard a satisfactory explanation. Both gypsum and rock-salt occur either in veins and strings, or in large beds, sometimes more than 100 feet in thickness.

Other minerals likewise occur, more especially in argillaceous rocks, though not so abundantly or in so distinct a form as those two. Many aqueous rocks are largely impregnated with iron, either simply as an oxide or iron rust, or combined with sulphur (sulphuret of iron, or iron pyrites). This latter mineral is often scattered about many rocks, either in cubical or dice-shaped crystals, or in balls or irregular masses, having a fine internal radiated structure. It is of a yellow colour and shining metallic appearance, and is frequently mistaken for gold or copper.

Another form of iron often occurring among argillaceous rocks, is iron in combination with a certain amount of carbonic acid, and called by the chemists carburet of iron; it is ordinarily termed Clay Ironstone. Beds of red oxide of iron, called Hæmatite, occur, associated sometimes with limestone. Some sands are so impregnated with iron as to have been used, and to be now used, in smelting furnaces, with great profit.

Copper itself is sometimes disseminated in some aqueous

rocks in sufficient abundance, as for instance in the *Kupferschiefer*, or copper slate, of Germany.

Silica is sometimes present in the aqueous rocks as a chemically formed deposit, having been held in solution in the water, and diffused through the rock deposited in it. This is especially the case with some limestones. It appears to have been diffused in small quantities through the mass of each bed as it was being formed, and to have subsequently segregated itself, by what is called chemical affinity, into either a regular layer, a vein, or a set of round irregular lumps called nodules. These silicious masses, when they contain a certain quantity of lime, are called "chert;" when nearly pure silica they are called "flint."

It often happens, whether in calcareous, arenaceous, or argillaceous rocks, that nodules of chert, flint, or other minerals occurring in a similar concretionary form, are disposed in regular layers forming lines on the face of a cliff, and that these mark the bedding or stratification of the rocks, when sometimes there is no other clear indication of it.

Some limestones consist not only of carbonate of lime, but also of carbonate of magnesia, mingled occasionally in pretty nearly equal proportion: when that is the case the rock is called a Magnesian Limestone, and also a "Dolomite."

CONCRETIONARY STRUCTURES.

The structures we have hitherto spoken of in this chapter are those of deposition,—the original structure the rock acquired from the very necessity of the conditions under which it was deposited. There are however other structures occurring in aqueous rocks, which may either have resulted during or immediately after their deposition, or may have occurred at any subsequent period. These are most common in calcareous rocks, or those which are mostly chemically formed,—as might have been expected. A common form of limestone is Oolite, or Roe-stone,—that is to say, a rock made of little round concretions, resembling the roe of a fish.

What is called Bath-stone and Portland-stone in England, or Caen stone in France, are oolites. Each of the little grains, rarely exceeding the size of a pin's head, would, if broken open, be found to be composed of concentric coats or shells, sometimes hollow in the centre, sometimes enveloping a small grain. I have observed this structure in some very recently formed stone, on the bank of a coral-reef.

When the little concretionary grains become larger, so as to be of the size of peas, the rock is called a Pisolite, or Pea-stone.

Some magnesian limestones—as, for instance, those of the North-east of England—sometimes assume a still more remarkable concretionary structure, forming balls, like bunches of grapes, musket-balls, or even cannon-balls. These balls are sometimes quite hard, and adhere firmly together, the rock around and between them being quite soft and pulverulent. That this concretionary structure is a superinduced one was shown long ago by Professor Sedgwick, who pointed out that the original lines of deposition or lamination of the rock might be traced through the whole mass, running quite even and parallel through the balls and matter outside of them.

Occasionally, though rarely, a somewhat similar structure, though not so thoroughly or completely carried out, can be traced in other rocks, especially in slightly calcareous or ferruginous sandstones, on a much larger scale. Blocks two or three feet in diameter have concentric circular bands of colour, marked near their outward surface. I have indeed seen in Australia a mass of such rock, consisting of several beds, traversed by concretionary spheroidal coats of some inches in width, and sufficiently distinct to make the rock split along them, each spheroid being at least twenty feet in diameter. These exceptional cases however are not

those which it is advisable to dwell on in so elementary a work as the present.

JOINTING OF ROCKS.

In addition to their separation into beds or strata, by pauses occurring during the act of deposition, all aqueous stratified rocks are separated by naturally formed planes of division cutting *across* the beds. These are called "joints." They cut across the beds at all angles both to the beds and to the horizon, and they also cross each other at all angles. There is however most commonly two principal sets of joints, both at right angles to the beds (without regard to the horizon) and also crossing each other at right angles, or nearly so. They thus have a tendency to divide all rocks into square-shaped or cuboidal blocks. These two sets of joints are apt to be a little irregular in their directions and in their distances apart, and are often slightly wavy; they are moreover frequently crossed by other joints in all manner of directions; it is consequently a rarity to find a true cubical block of rock, naturally formed. If it were not for these joints, quarrying for stone would be next to an impossibility. They seem to be caused by the contraction of the rock on solidifying. I have always seen

them very well marked in the recently formed coral limestone found on small islets on coral-reefs, composed of the calcareous sand, compacted together into a loose semi-coherent stone.

The rocks thus briefly described are associated and grouped together in every imaginable way. In some cases we may find bed over bed of purely calcareous, or arenaceous, or argillaceous matter, no one bed differing sensibly from those above or below it, the whole mass acquiring a thickness of many hundreds of feet. Single beds, sometimes of very inconsiderable thickness—say one to two feet only—will occasionally spread over an area many miles in extent in every direction. A series or group of beds, of a thickness of several hundred feet, will even spread for hundreds of miles in every direction. In other cases, beds of different mineral composition will alternate rapidly one with the other, so that within a vertical thickness of one hundred feet we may have beds of sandstone, clay, shale, limestone, calcareous sandstone, sandy shale, and argillaceous or arenaceous limestone.

The way in which beds of different mineral character alternate with each other, may be seen in Plate XI., where

we have beds of hard sandstone and softer marls or shales interstratified, resting on other and thicker beds of hard sandstone and conglomerate. Any one of these beds may either spread as a continuous sheet over a very wide area, or may be of comparatively small extent—a mere cake, as it were, of a few yards in diameter, ending and thinning out gradually in all directions.

Two beds of sandstone or limestone resting one upon the other with nothing between them, may sometimes be found, if we trace them in one direction, to become divided by a thin seam of clay or shale. This thin seam may gradually increase in thickness as we follow it on, till it becomes a very considerable bed. It happens sometimes that, if we trace it yet further, this bed will itself become split into two, then into more; other beds, either of sandstone or limestone, will begin to make their appearance in it; until at length the two first beds, which when we first saw them rested one upon the other, become separated by many feet or many yards of interposed material. One or other, or both, of those two beds might then thin out and disappear.

When we had observed a few instances such as the above, or other gradual changes that might be enumerated, we should then be prepared to understand the following:—

A group or series of beds, which in one place consists entirely of one set of materials, may in another consist of an entirely different set.

For example, a series of beds of almost pure limestone, say 800 or 1000 feet in thickness, may, by the gradual interposition of shale and sandstone and their increase in thickness, and the simultaneous thinning of the limestone beds, pass—in the course, say, of fifty miles—into a group of shales and sandstones, with few or no calcareous beds.

Similarly, a great group of beds, in one place consisting of sandstones, marls, and conglomerates, in another place may be composed entirely of clay-slate and limestone.

Again, a set of beds, in one part of the world composed entirely of soft white chalk, in another may be entirely hard black marble, and in a third may be clay-slate and sandstone.

These may seem to be rather dry and barren statements; they are not entirely so. They have an interpretation: a story, if only a fragmentary one, may be deduced from them. We saw that from the *structure* of the aqueous rocks we could reason back to the nature and to the varied play of the agencies that produced them. The *grouping* of these rocks gives us similar information.

Take the case of the two beds of limestone or sandstone mentioned at p. 56. We learn that, after the first was deposited, there was a very considerable interval before the formation of the second, although when we first found them resting one on the other, there was nothing to tell us of that interval. The first-formed or lowest bed rested at the bottom of the water, and into that water was swept on one side a quantity of silt, mud, and sand, that was carried a certain distance, and then fell to the bottom; some of it, especially of its finer portion, was carried further than the other, but none of it reached so far as the place where we first found the beds. At that place, during the whole of that interval, the water remained unsullied with mechanical detritus, and not sufficiently impregnated with mineral matter to cause a deposition to take place. After that interval, perhaps after a still longer one, another deposition took place, and the upper bed was formed, resting in one part directly on the lowest, and in the other, on the interposed materials.

In the case of great groups of rocks changing entirely their mineral character, we learn, among other things, that at the time those groups were deposited, Nature acted much as she now does; that the surface of our globe was not one

uniform sea, but broken by land and water; and that the refuse and detritus washed from the land into the water, was of as various a character as it is now. While in some wide-spread and tranquil seas chemical precipitations were taking place, in other parts of the same seas mechanically suspended and transported materials were being brought in, just as we know must now be taking place in our present seas.

We are thus shown that these rocks were not formed by any mysterious or inscrutable agency, acting by means or on a plan which we cannot discover or cannot understand, and are therefore left to guess at or conjecture about; but by the simple action of those natural agencies which surround us continually on every side, and are open to our observation in our daily walks.

To the unobservant the world is a riddle, a heap of wonders, a conjuror's box; to the observant, an admirable and beautiful piece of mechanism, for ever at work for his instruction and delight; the agencies and the action for ever varying, like the strains of a piece of music or the harmony of a poem, but all combining to one end, all obeying the impulse of one law, all tending to one great system of order and arrangement.

CHAPTER IV.

THAT SOME ROCKS HAVE BEEN MOLTEN BY HEAT, AND
ARE THEREFORE CALLED IGNEOUS ROCKS.

I MUST now beg the reader to turn suddenly to a totally different part of our subject, and to examine with me the phenomena of Volcanoes. As we have happily no native example to which we can refer, we are obliged either to travel abroad, or to trust to the accounts of others, in order to study the results and the effects of volcanic agency. In Sir C. Lyell's 'Principles of Geology' there is a succinct history of volcanoes, in which, and in the authorities to which he refers, the reader will find many details as to the structure of particular volcanic districts, or the effects of particular eruptions*. It will suffice here if we give a few

* Another easily accessible book is Dr. Daubeny's 'History of Volcanoes.'

of the characteristic features common to all volcanoes and to all eruptions.

A volcano is generally a more or less perfectly conical mountain, composed very largely of pumice, ashes, and scoriæ (cinders), with streams of rough black rock (cooled lava) running down its sides, and spreading here and there about its base. There is commonly at its summit a basin-shaped hollow, or crater, which during periods of eruption is open either entirely or partially; and from this orifice are belched forth showers of red-hot stones, ashes, steam, gases of various kinds, sometimes inflammable, and sometimes melted rock or lava, which, forced up over the lip of the crater, rushes like a torrent down the sides of the cone. More often however the upper cone and its crater-form summit, being composed of mere ashes and loose ejected masses, is not able to sustain the pressure of the great central column of lava, which then forces an exit for itself near the foot of the cone, or in some lower part of the mountain, wherever circumstances cause a weak point, to allow of its passage.

If we were to examine the flanks of a volcanic range, where river action or that of the sea had worn cliffs and ravines in its sides, and thus exposed its interior structure,

we should find it composed of alternations of hard black rock in irregular beds or sheets, beds of ashes, cinders, or pumice, and beds of a fine-grained compact rock made of the small stones, or fine sand, or powder blown into the air from the crater, and falling equally around it. We should thus perceive that not only the cone now active, but the whole mountain mass from which it rises—which in the case of a single mountain like Etna is ninety miles in circumference, in the case of a chain like the Andes is one hundred or two hundred miles wide, and some thousands in length—is entirely or in great part made up of volcanic products. The effects of single eruptions, such as the fall of ashes and powder in sufficient quantities to darken the sky, have been known to extend even hundreds of miles from the orifice whence they were blown out. Great streams of lava, some miles in width, and fifty or a hundred feet in depth, have been known to run for twenty or thirty miles in length, filling up the hollows of lakes and the valleys of rivers, and totally obliterating the old features of large tracts of country. The sides of great volcanic mountains have been frequently rent by long fissures, which have been filled with molten rock, and these, when cooled and consolidated, act the part of great ribs and bars, supporting the framework of the struc-

ture. These stand out of the sides on the cliffs or ravines, or on the worn flanks of the mountain-like walls, projecting by reason of their superior hardness, having resisted the erosive action which formed the cliff or ravine, in a greater degree than the softer materials about them.

Volcanoes may be of two kinds,—those formed on dry land, and therefore called subaerial, and those formed under the water, or submarine. Inasmuch however as submarine volcanoes must always have a tendency, if only from the piling up of materials, to raise their tops above the water, it may often happen that a volcano may have been submarine as to its lower parts, and subaerial as to its upper portion.

Moreover, as we shall see hereafter more particularly, earthquakes are ordinary accompaniments of volcanoes, and prevalent in volcanic districts, and one effect of earthquakes is the permanent lifting up or elevation of the land. It may therefore often happen that even those portions of a volcanic district that were formed beneath the sea, may be subsequently raised above it and laid open to our examination. From observations on such portions we may arrive at a knowledge of the results of volcanic action beneath the sea, which will serve to render more complete the information derived from the study of subaerial volcanoes.

In a small ravine, about a mile from the town of Santa Cruz, in the island of Teneriffe, I once observed the following section, of which I made a rough sketch on the spot. (Plate XII. in which however the columns are much too regular.)

1. Basaltic lava, rudely columnar, about twenty feet thick.
2. Conglomerate of volcanic sand, and rounded blocks of lava and basalt; its upper boundary very irregular; the thickness of the whole varying from one to four feet.
3. Red, coarse volcanic grit, with a band of grey ditto.
4. Red grit of finer texture.
5. Yellow sand very finely laminated.

These materials (3, 4, and 5) were most regularly stratified, perfectly parallel and horizontal as far as the section extended, which was about fifty yards. They were altogether about five feet in thickness.

6. Conglomerate like No. 2, but more regular, and about four or five feet thick.

7. The upper surface of a bed of rudely columnar basaltic lava, like No. 1, forming the bed of the ravine.

From the rounded and water-worn appearance of the blocks in the conglomerate, and from the perfectly sifted and stratified appearance of the sands, I concluded that these beds were formed under water, and that therefore No. 7,

and in all probability No. 1, were lavas that were poured out under water, whether they proceeded from a submarine volcanic vent, or were parts of lava-streams that had flowed from the land into the sea.

In order to gain a little more precise idea of the structure of a volcano, let us trace the history of an imaginary one, by the light of the information we now have respecting them. Let us suppose the first volcanic orifice to be opened beneath the sea. We will not stop to puzzle ourselves with the cause of this orifice, nor whether it is a simple crack or a dome-shaped elevation of the pre-existing rocks swelling like a bladder till it opens at the centre. Such matters (still disputed points among geologists) do not belong to so elementary a work as the present one*. Let it suffice that an orifice is produced, through which the heated matter

* I may be pardoned perhaps for mentioning in a note, that in the Peak of Teneriffe the great broken wall encircling the Pumice Plains (from one corner of which plains rises the present cone) with its beds, having a quaquaversal outward dip, and which Von Buch describes as a clear case of "erater of elevation," appeared to me to be nothing more than the ruins of the outer wall of an old crater made up of alternations of pumice and lava, etc., and therefore to have been *produced by the volcanic action*, in which case it could not have been elevated at its first appearance. The tilted beds round a true "erater of elevation" ought not to be volcanic, or they do not bear on the question of the origin of the volcano.

of the interior forces its way to the surface. Doubtless this would hardly take place without a rending and shattering of the earth's crust which would produce what we call an earthquake.

The next effect would probably be the violent ejection into the superincumbent water of shattered pieces of rock, and the boiling up and overflow of a mass of molten lava that would spread in a sheet along the sea-bottom according to its shape. This sheet of lava would probably always be rather more regular, horizontal, and equally diffused, than a sheet of lava on the land. In each case it would probably end, not by a gradual thinning out, but abruptly with a steep slope. It would also cool more slowly than subaerial lava, because water, especially under pressure and when it could not form steam, would carry away heat less rapidly than air. Whether anything resembling ashes, dust, or powder, such as we see blown from land-volcanoes, could be ejected from submarine ones under the pressure they would be subjected to, may admit of a doubt. Much would depend on the depth of the sea, as to the possibility of matter being thus as it were blown to atoms. Whatever the depth might be however, we can hardly conceive it possible that with so sudden and so large an accession of heat there

should not be very considerable currents of ascending hot water, and of lateral cool streams flowing in to replace it. All the lighter materials therefore might be carried off to great distances, and there must to a certain extent be an erosion or wearing away of the harder and heavier ones, the detritus being strewed in beds on the surrounding sea-bottom, just in the same way as sand swept into a sea from a coast would go to form a sandstone.

As the increase of materials went on, and the volcanic vent was thus lifted toward the surface of the sea, the diminution of pressure would allow of the production of lighter and more cindery materials ; and when it was lifted up a little above the sea-level, if not before, we should certainly have ashes and powder ejected into the air and falling in the surrounding sea*. Now in this case we should have some

* In 1842 I landed for half an hour on an interesting specimen of a volcanic island in the South Indian Ocean, called the Island of St. Paul. Except another similar island about twenty miles north of it, and Kerguelen's Land on the south, it is the only spot of land within 2400 miles. It is $3\frac{1}{2}$ miles across and 820 feet high at the highest point. It consists of a circular crater with its surrounding walls, and a strip of lower ground all round except on the eastern side : on this side the mound had been cut down below the sea, leaving a bank of soundings only, stretching out a mile or a mile and a half ; and the sea had thus gained access to the crater. As we passed in in the boat we found not more than three feet water on the bar of the crater, but

rocks which were simply cooled from a molten state, and we should have the detritus of those rocks; we should also have rocks composed of volcanic sand or dust, which nevertheless, in all their characters of stratification, etc., were truly aqueous rocks, having fallen to the bottom of the water in a state of mechanical division, and been strewn into regular beds, as if they were sandstones and shales.

Moreover it is important to recollect that in many cases this volcanic action would not be continuous: the fires might die out and lie dormant for centuries*. Aqueous

inside in the centre it was thirty fathoms deep, with a bottom of fine black mud. On the south side of the entrance the wall of the crater had been cut back to a ridge a few feet wide. The crater was about half a mile wide. The water in the centre, both at the surface and at the bottom, had a temperature of 54° , which was that also of the sea outside, (this was on August 5th); round the margin of the crater or its beach however were several streams and springs of hot water. One of these had a temperature of 138° , but on removing a few of the stones, and letting it flow more freely, it rose to 150° . The island seems principally composed of sand, ashes, and blocks of hornblende lava. The beds, so far as I could observe in the cliffs, dipped very slightly in any direction, and at one part seemed to have a decided inclination towards the crater. The whole island was covered with a long coarse grass, except the cliffs of the coast and those forming the uppermost three hundred feet or so of the walls of the crater. (See Sketch, Plate XIII.)

* Vesuvius had lain dormant for six or eight hundred years before the eruption in A.D. 79.

rocks therefore might be deposited on the bottom of the sea upon the igneous ones, these aqueous rocks being shales, sandstones, limestones, or any other kind. Then another eruption might take place, and so on; so that in the submarine roots of a great volcanic mountain there may be every imaginable variety of alternation and entanglement between true igneous rocks, aqueous rocks of igneous material, and ordinary aqueous rocks. As every successive eruption would be accompanied by disturbing forces producing fissures, it would often happen that molten lava would gain access to those cracks, and fill them up to a greater or less extent, producing walls of rock (or dykes, as they are called) cutting through all the other rocks.

When our supposed volcano has once reared its head above the waves and become dry land, it can increase only by direct igneous action,—that is, either by the vomiting forth of broken materials into the air, or by the ejection of streams of molten lava down its sides. The blocks, lumps, sand, ashes, pumice, and powder, blown from the crater, have always a tendency to fall equally all round its sides, and thus rear a symmetrical cone; those matters light enough to be acted on by the wind however would of course be carried by it more in one direction than another. The

lapilli and powder fall sometimes in such quantity as to make thick deposits, that become converted into a kind of stone called "tuff."

When the volcano has grown to a considerable magnitude by the successive additions of these materials, ejected from one focus, it often happens that in some following eruption it breaks out on the side or near the foot of the mountain; a new cone is then formed on a smaller scale, which is probably itself subsequently covered up and buried by accumulations derived from the old, or from still newer vents. It is probable therefore that if we could take any large volcanic mountain, such as Etna or Teneriffe, and dissect it, so as to observe the successive steps of its formation from the commencement, we should find it possessing a most curiously complicated structure. Its roots would probably consist of hard compact or crystalline igneous rocks, interstratified with aqueous ones; its upper part, of coat upon coat of ejected matters, first upon one side, then upon another, the great cone blistered all over as it were with little minor excrescences here and there, many concealed and buried under more recent ejectamenta; the whole penetrated in various directions by veins or walls of rock more or less nearly upright.

Mineralogists and mineralogical geologists have given us a vast variety of names for the different varieties of volcanic products, some of which may be useful and some merely perplexing. These will be described as far as necessary in the next chapter.

In order that we may have some notion of the extent to which volcanic action is now going on in the globe, I will briefly enumerate the known volcanic districts. A band of country, containing volcanoes or exhibiting more or less of volcanic agency, stretches from the centre of Asia to the Mediterranean. In the Mediterranean we have the volcanoes of Santorin in the Grecian Islands, of Vesuvius, Ischia, and Etna. In the Atlantic we have Hecla, Madeira (extinct), the Canaries, Cape Verds, Azores, St. Helena (extinct), Ascension, and the small islands of Trinidad* and of Fernando Noronha. One of the lines of the West India Islands is volcanic, being probably a branch from the Andes. In South America the whole line of the Andes, from Tierra del Fuego to the Isthmus of Panama, is volcanic. This line,

* The small islands of Trinidad in the Atlantic Ocean must not be confounded with the large island of Trinidad in the West Indies. From a want of caution on my part, some facts which relate to the little islands in long. $29^{\circ} 35' W.$ lat. $14^{\circ} 53' N.$, are quoted by Dr. Daubeny, in his 'Description of Volcanoes,' p. 467, as applying to the larger island.

running nearly north and south, is crossed by another in Mexico running east and west, which is perhaps continued to the volcanic islands of Revellagigedo on the west, and in some way connected with the West Indian line on the east. We have too in this region the volcanic group of the Galapagos and the extinct volcanic island of Juan Fernandez.

The Rocky Mountains of North America appear in part to be volcanic, but their fires are now either dormant or extinct.

In the Aleutian Islands we have the commencement of one of the greatest and most active of the volcanic bands in the world stretching thence through Kamtschatka, the Japanese Islands, Formosa, the Philippines, and the Moluccas, to New Guinea. From the Moluccas this band extends through Flores, Sumbawa, Lomboek, Bali, Java, and Sumatra, up to Barren Island in the Bay of Bengal. From New Guinea, it runs in the other direction, by New Ireland and the New Hebrides, and other intermediate islands, down to New Zealand and the Chatham Islands.

In the Pacific Ocean we have also volcanoes in the Sandwich and the Friendly Islands, Tahiti and some of the Society Islands (extinct), as also the extinct groups of the Marquesas and others.

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Hrilmandel & Walton, Lith

SAND AND GRAVEL PIT, NEAR BARRACH, CO. CORK, IRELAND.

In the Indian Ocean we have the little islands of St. Paul and Amsterdam, Mauritius (extinct), and Bourbon; further south are Crozet's Islands and Kerguelen's Land; and in the Antarctic Ocean the volcanoes of Mount Erebus and Mount Terror, in the Victoria Land of Captain Ross.

There is therefore no large portion of the globe, if we except Africa—of which we know so little—free from the effects of volcanic power.

If we were to include all extinct volcanoes, of which the fresh marks still exist, such as uncovered and undecomposed beds of lava, or even undestroyed craters, we might describe Central France, part of Germany, Spain, the colony of Victoria in Australia, Van Diemen's Land, and many other parts of the globe, as volcanic.

Now as these volcanic forces have been so widely spread, and as their effects are everywhere pretty much the same, it is clear that their cause can be no partial or local one, but one deep-seated and common to the whole globe. When we reflect moreover that earthquakes are intimately connected with volcanoes, that they precede or accompany volcanic eruptions, and that they sometimes shake whole continents; that the earthquake and the volcano are but two external symptoms as it were of the same internal force, we

shall feel still more sensibly how deep-seated and universal that power must be.

As we have seen that molten rock does in many instances succeed in forcing its way to the surface either of dry land or the bottom of seas and lakes, we should naturally expect that there might be also many cases in which it did not so succeed, but lay buried still in the interior of the earth, and after a time cooled where it was. Moreover, as the lava-stream of a volcano is merely the boiling over of a vast quantity of melted stone deep below ground, and the part reaching the surface must be a small portion of the whole mass, it must happen sometimes that a great portion of the remainder of the molten rock will cool down ultimately in the interior of the volcano, and perhaps pretty low down under a great pressure of other rock, and much more slowly than the actual lava. It might be naturally anticipated that the rocks, when thus cooled down, slowly and under great pressure, and perhaps without the access of either air or water, would exhibit somewhat a different structure from the volcanic rocks.

Whenever we examine rocks therefore that had once been deep-seated, but which are now exposed to our observation, we should expect to find here and there some that, though

of truly igneous origin, yet were not exactly similar either in structure or perhaps in composition to those which we find on the surface of volcanoes. As a matter of fact we do find such rocks, which we know to be igneous ones for the following reasons :—

First, some of them do resemble, in structure and other characters, some of those which we know to be the products of volcanoes.

Secondly, when we find them in connection with aqueous rocks, we perceive that they are not regularly *interstratified* with them, but often intrude irregularly among them, sometimes in vertical walls cutting through them, sometimes in rude shapeless masses, sometimes in fine branching veins, running for many yards through the aqueous rocks, splitting up into narrow strings, and twisting in various directions. This takes place in such a way that it is plain the aqueous rocks were first formed, and have then been disturbed, broken, and cracked in various directions, the cracks being filled up by the intrusion or injection of the other rock in a fluid state*.

* See Plates XIV. and XV. In Plate XIV. the central portion represents a vertical wall or mass of igneous rock, which had cut up through the regularly stratified limestone on each side of it. In Plate XV. a darkly shaded band

Thirdly, it is shown that this fluidity was the result of great heat, in fact a molten fluidity, because the aqueous rocks near these injected masses have evidently undergone such an alteration as is the effect of heat; that alteration being greatest, closest to the intrusive rock, and dying away as we recede from it. For instance, we find soft sandstones hardened or half-fused into quartz rock, shales baked into jasper or Lydian-stone, or into a substance resembling porcelain, chalk altered into crystalline marble, coal converted into cinder, or into a substance resembling coke.

Rocks that have the characters of these intrusive masses, dykes, or veins, must be igneous rocks, and such are the rocks called Basalt, Greenstone, Feldspathic Trap, Syenite, and Granite.

As the aqueous rocks are all stratified more or less completely, and often go by that designation, so these rocks, never having any true stratification (however they may sometimes assume its appearance), are often called Unstratified rocks. In order to distinguish them from volcanic rocks, the

of greenstone is seen cutting through the thin-bedded limestones, and at one place branching into two veins, one of which again subdivides and ends in strings, the other disappearing before it ends at the top of the cliff.

terms Hypogene and Plutonic have been applied to them, both indicating that they have been formed or brought into their present state *below ground*, while Volcanic rocks have always been ejected above the surface of the earth, whether that surface were there covered with water, or only with air.

While this was passing through the press the following paragraph appeared in the newspapers, and is interesting in connection with the imaginary history of a submarine volcano and the consequent currents. (See p. 67.)

“Information was recently received at Lloyd’s, of an extraordinary marine convulsion experienced by the ‘*Maries*’ on her passage from Liverpool to Caldera. On the morning of the 13th of October, the ship being twelve miles from the equator, near W. long. 19° , a rumbling noise appeared to issue from the ocean, which gradually increased till the uproar became deafening: the sea rose in mountainous waves; the wind blowing from all quarters, the control over the ship was lost, and she pitched and rose frightfully, all on board expecting each moment to be their last. This continued fifteen minutes; the water then gradually subsided, when several vessels in sight at the commencement of the convulsion were found to have disappeared. Shortly afterwards a quantity of wreck and a part of a screw-steamer were passed, so that some vessels and lives were lost.”

CHAPTER V.

COMPOSITION AND STRUCTURE OF IGNEOUS ROCKS.

WHEN describing the composition of aqueous rocks, we had occasion to allude to some of the more simple facts and principles of chemistry,—to speak of the precipitation and crystallization of certain substances that were held in solution by water. In treating of the igneous rocks, we must, inasmuch as they are all chemical compounds, penetrate a little further into chemistry and mineralogy, or rather we must be able to understand and make use of some of the results which chemists and mineralogists have arrived at.

I will endeavour then in this chapter to explain, and as far as possible to translate into popular language, such of the facts and statements of those two sciences as will enable the reader to understand the composition of igneous rocks.

To do that it will be necessary first of all to describe certain minerals, some of their more obvious characters and properties, and what they are made of, and then to show how these minerals combine among themselves to produce different varieties of rock*.

To describe minute varieties of minerals by their external characters and properties, so that they can be recognized from such description, is almost impossible, and would certainly require more room than we have to spare. The student must see specimens of them, and study them for himself. There are however four kinds of mineral substances which most commonly occur in igneous rocks, and of these I will endeavour to give a rough description first of all.

These minerals are Quartz, common Feldspar, common Hornblende, and common Mica.

Quartz has been already spoken of at p. 5. It is commonly either clear and transparent like glass, or opaque and milk-white. It is always very hard and will scratch glass, while it cannot be scratched with a knife.

* In this task, as I do not pretend to be either a chemist or mineralogist, I have been greatly assisted by my colleagues, Messrs. W. K. Sullivan, Chemist to the Museum of Irish Industry, Dublin, and Mr. H. B. Medlicott, of the Irish Geological Survey Office, Dublin. I have used as works of reference, Sir H. De la Beeche's 'Geological Observer,' Professor Nicol's 'Manual of Mineralogy,' and Daubeny's 'Description of Volcanoes.'

Common Feldspar is always opaque, generally white or flesh-coloured; when crystalline occurring in flat oblong crystals, with a satiny lustre, and splitting into plates. It is always softer than quartz, and can, though with some difficulty, be scratched with a knife.

Common Hornblende is an olive-green or brown mineral, so dark as often to appear black; it has frequently a silky lustre. The form of its crystals is not easily described, nor very obvious in rocks. It is rather softer than feldspar.

Mica is commonly a greenish or yellowish-brown mineral, but sometimes assumes every variety of colour, with a decided metallic lustre and appearance, so as to have been often mistaken for gold or silver. It easily splits into thin elastic plates, which are sometimes mere spangles, but are sometimes so large, that, being as transparent as the horn used for lanterns, the plates have been used in Russia for window-glass. Mica is very soft, so as to be easily cut with a knife.

For the chemical composition of these and a few other minerals, it is necessary we should be a little more precise in our descriptions, and, for that purpose, that we should begin at the beginning.

All physical substances whatever, animal, vegetable, or

mineral, air, earth, or water, are either simple elementary substances, or combinations of two or more elementary substances. There are about sixty* elements or simple substances, of which three or four are commonly known to us as gases, such as oxygen and hydrogen; nine as non-metallic solids, such as sulphur, phosphorus, carbon, silicon; and the rest are metals. Of the metals some are those ordinarily known as such, like gold, silver, iron, copper, tin, mercury, etc., but others are never seen as metals except when artificially reduced to that state, such as potassium, sodium, calcium, magnesium, aluminium, etc.

These simple substances combine with each other, not indifferently, but with greater or less readiness, and in certain given proportions, according to fixed laws. These combinations produce other substances often having totally different characters and properties from either of their elements when uncombined; and these compound substances will likewise combine among each other only according to certain fixed laws, and in certain given proportions, to produce other substances. These combinations, or *unions*, must be carefully distinguished from mere *mixtures*. In a chemical

* Chemists are not quite sure about two or three, whether they are simple substances or not.

union or combination, the combining substances, whether simple or compound, often disappear, as it were, and are utterly lost, so far as external appearance or external properties are concerned, in the new substance produced by their combination.

Oxygen is the simple substance that most universally combines with all the rest; with most of them it will combine in one or more definite proportions. When it combines with another substance in the proportion of one equivalent of each, the result is called a protoxide; when there are two equivalents of oxygen to one of the other, the result is a binoxide or deutoxide; when there are three equivalents of oxygen, a teroxide or tritoxide; and when it is combined in the highest proportion it is capable of, with any particular substance, (whatever proportion that may be,) the result is called a peroxide.

When oxygen combines with some substances, or when it combines in high proportion with some other substances, the result is an acid. Many of these acids are what the word ordinarily means, namely, *sour*, but all are not; the term *acid* in chemistry having a technical meaning, denoting a substance which combines fiercely, as it were, with some other, and which acts strongly on certain metals, and so on.

The substance with which an acid combines is termed the Base, and the substance resulting from the union of an acid with a base is technically called a Salt.

Oxygen combines more readily with some metals than with others. The oxygen of the atmosphere or of water combines more readily with iron than with gold. Iron-rust is an oxide of iron. Every one knows that iron rusts more easily than gold.

With some metals however oxygen unites so eagerly and fiercely, as literally to burn them up almost as soon as it gets access to them. These metals are those called Potassium, etc., mentioned before. As soon as either air or water comes in contact with them, under certain conditions of temperature, etc., the oxygen of those substances unites with the metals, producing great heat and flame, and the resulting substances are those called the Earths and Alkalies.

It was at one time thought that there was a metal Silicium, the union of which with oxygen produced silica. It is now however believed that the element of silica is a non-metallic substance, such as sulphur or carbon; it is therefore called Siliceon. The union of oxygen with these substances produces the Sulphuric, Carbonic, and Silicic acids.

Of these Silicic acid, or Silica, is the only one we commonly see in a solid or earthy form.

We will now enumerate the principal secondary substances (formed of the union of oxygen with another elementary substance) which enter into the composition of the minerals forming igneous rocks.

Silica—a peroxide of Silicon.

Alumina—a sesquioxide* of Aluminium.

Lime—a protoxide of Calcium.

Potash—a protoxide of Potassium.

Soda—a protoxide of Sodium.

Magnesia—a protoxide of Magnesium.

Lithia—a protoxide of Lithium.

Sulphuric Acid—a tritoxide of Sulphur.

Also protoxide and peroxide of Iron.

And protoxide of Manganese.

Now as Silica is an acid, it can unite with the other substances as bases. Just as we saw before, at p. 28, that carbonic acid united with lime, in order to form carbonate of lime, so silica can form a silicate of lime, and, by uniting in a double or treble proportion, a bisilicate, trisilicate, etc.

* *Sesqui* is Latin for “one and a half;” a sesquioxide therefore is a combination with one equivalent and a half of oxygen.

Alumina is supposed to have somewhat of the same property, only in a less degree, as there are aluminates of some of the earths.

In order that silica should combine with a base however, it is necessary to raise it to a high temperature, or to heat it along with the other substance it is intended to combine with. If silica be by itself exposed to heat, it remains unchanged, except by the most intense temperature that can be produced in a laboratory ; but if potash or soda be mixed with it, a far lower degree of heat will cause the two to combine and melt together into a glass. The earth or alkali is often said to act as a “flux” to the silica. Glass, porcelain, or even pottery, are silicates of some of the earths and alkalies, mingled according to certain proportions, in order to produce the required results. By the mingling of the substances enumerated above, products are often formed in our laboratories, furnaces, glass-houses, etc., whether by accident or by design, bearing a more or less exact resemblance to the igneous rocks produced in the great laboratories and furnaces of nature. This is another proof of the igneous origin of the rocks composed of those substances.

There is yet one other chemical law that must be explained, before we proceed, and that is what is called the

law of Isomorphism. There are certain substances which are called *isomorphous*, or *identiform* (to replace the Greek term by a Latin one), because they can replace each other, or become each other's substitutes, without producing any change in the form, or even in many of the properties, of the body they exist in. For instance, this replacement or substitution can take place in any proportion between lime, magnesia, protoxide of iron, and protoxide of manganese; or between alumina and peroxide of iron. A mineral therefore can vary greatly in some of its minor characters, such as colour, and in some of its minor constituents, and yet still remain the same mineral. It remains the same so long as the relation between the acids (or what act as such) and the bases (taken as a group when isomorphous) remains the same.

We will now proceed to describe the chemical composition of the four minerals mentioned before, and of a few others.

QUARTZ—is almost pure silica, containing never less than 95 or 97 per cent. of that substance, the remainder being a slight admixture of alumina, lime, peroxide of iron, or protoxide of manganese.

Pure colourless quartz is called “rock crystal,” “Bristol

diamonds," "Irish diamonds," etc. Amethyst is quartz supposed to be coloured violet-blue by peroxide of iron. Cairngorum pebbles are smoky or yellow quartz. Jasper is quartz variously coloured by iron in different states. Hornstone or chert, flint, Lydian-stone, chalcedony, carnelian, agate, onyx, bloodstone, are all quartz with slight admixtures of other matters, giving rise to the varieties in colour, transparency, etc. Opal is quartz with from five to ten per cent. of water, chemically combined with it.

FELDSPAR.—This is the name of a group or family of minerals rather than of one. They are all essentially silicates of alumina, combined with silicates of some alkali; they are therefore nothing else than a kind of opaque glass*.

The principal feldspathic minerals admit of a threefold division, according to the variation in the proportion of the silica to the other ingredients. This variation takes place with respect to the alumina (peroxide of aluminium) and its isomorph, peroxide of iron, while the proportion of silica combined with the alkali or earth, or its protoxide isomorphs,

* Glass, as generally manufactured, is a silicate of potash or of soda, or of both, mingled with one or more insoluble silicates of the earthy bases, such as lime or baryta.

remains always the same. The variation is in the proportion of the numbers 1, 2, and 3, in this way :—

In the first group of feldspars we have a silicate of the protoxide bases + a silicate of alumina or the peroxide bases.

In the second group of feldspars we have a silicate of the protoxide bases + a bisilicate of alumina, etc.

In the third group of feldspars we have a silicate of the protoxide bases + a tersilicate of alumina, etc.

In the first group are the minerals labradorite, anorthite, etc. In the second, oligoclase, andesine, etc. In the third, orthoclase, adularia, albite, pericline, etc.* Of these minerals, it will be sufficient to give the normal† analyses of the following :—

1. Labradorite contains—silica, 53·69; alumina, 29·68; lime, 12·13; soda, 4·50.

2. Oligoclase — silica, 62·37; alumina, 25·86; soda, 11·77.

* Daubeny's 'Description of Volcanoes.'

† By *normal* here is meant the calculated or theoretical analysis, which follows from the chemical formula or expression describing the composition of the mineral. In consequence of the law of isomorphism, the actual analyses of different specimens may vary within certain limits indefinitely from the normal analyses.

3. Albite—silica, 69·25 ; alumina, 19·13 ; soda, 11·62.

4. Orthoclase—silica, 65·35 ; alumina, 18·06 ; potash, 16·59.

Labradorite and anorthite are often spoken of as the Lime Feldspars, from their containing lime in their protoxide bases. Oligoclase is likewise called Soda Spodumene. Albite is called Soda Feldspar, from its containing soda as a base. Orthoclase is similarly called Potash Feldspar, and also Common Feldspar, or Feldspar *par excellence*, being the variety most abundantly met with in rocks.

HORNBLLENDE.—This is likewise a name for a family of minerals, rather than for any one in particular, although the term Pyroxene is perhaps more generally applied to the family, and Hornblende to one member of it ; instead of pyroxene, the word Augite is sometimes used. It is indeed very difficult to arrive at any clear notions with regard to this group of minerals from the present works on Mineralogy. The Hornblendic minerals may be said to be essentially silicates of lime and magnesia, and their isomorphs protoxide of iron and of manganese.

There are two principal minerals in this family, namely, Hornblende or Amphibole, and Augite or Pyroxene, though mineralogists seem to be in doubt whether these two are

not really one mineral under slightly different forms. It has been supposed that when cooled rapidly it might be augite, while if cooled more slowly it might be hornblende. Hornblende appears to be always richer in silica than augite, except when part of the silica is replaced by alumina.

Owing to the law of isomorphism in the bases of these minerals, their actual analyses are very various, as not only the substances mentioned above vary, but alumina also comes in sometimes, apparently acting as an acid, and replacing some of the silica.

The following is a mean of several analyses of Hornblende:—silica, 46·63; magnesia, 16·24; lime, 12·63; protoxide of iron, 11·27; alumina, 11·16. For Augite we have the following analysis:—silica, 56·36; magnesia, 18·18; lime, 25·46.

Actinolite and some kinds of asbestos are forms of hornblende. Diallage is a variety of augite, generally of a green colour, and splitting into folia. Hypersthene is nearly the same as diallage, but contains generally a large proportion of iron and little lime.

MICA.—This mineral, like feldspar, is a silicate of alumina, combined with a silicate of either potash, lithia, or magnesia; the varieties however are not so easily distinguishable, and

have been less frequently distinguished than those of feldspar. Common mica is the potash mica, the normal composition of which is stated as—silica, 48; alumina, 39·8; potash, 12·2. Part of the potash is occasionally replaced by protoxide of iron or manganese, and of the alumina by the peroxides of iron.

Lithia mica, or Lepidolite, is more fusible than potash mica; its normal composition is—silica, 51·6; alumina, 28·5; potash, 8·7; lithia, 5·3; fluoric acid, 5·9; but often containing much protoxide of iron and manganese.

Magnesia mica, or Biotite, contains from 10 to 25 per cent. of magnesia, and only about 12 to 20 of alumina. The analyses do not admit of a normal formula, and vary greatly; the following is a selected one:—silica, 42; alumina, 16; iron peroxide, 5; magnesia, 25·9; potash, 7·6.

Chlorite is a micaceous mineral, being a silicate of alumina and magnesia, with iron and water chemically combined. It is a soft, green mineral, splitting into thin plates. The analyses are various, one of the normal forms being—silica, 26·3; alumina, 21·8; magnesia, 25·5; protoxide of iron, 15; and water, 11·5.

Talc and Steatite are said to be different forms of the same mineral, and to be chiefly a silicate of magnesia, with

some protoxide of iron, and rarely a little alumina. The normal analysis is—silica, 63·9; magnesia, 36·1; a part of the latter often replaced by protoxide of iron. There are a few other minerals which either enter into the structure of igneous rocks, or are associated with them frequently enough to render it useful to mention them: these are olivine, schorl, tourmaline, leucite, epidote, and the zeolites.

Olivine is a silicate of magnesia and protoxide of iron; when transparent and perfectly crystallized, it is called Chrysolite.

Schorl and Tourmaline are the same mineral, one having a great variety of chemical composition, being apparently a silicate of alumina, associated with magnesia, lithia, lime, soda, or potash, and having always some boracic acid.

Leucite is a silicate of alumina and potash; its normal chemical composition being—silica, 55·7; alumina, 23·1; potash, 21·2; the same components as in orthoclase or potash feldspar, but in different proportions.

Epidote is one of the garnet family; it is a silicate of lime, with a silicate of alumina; the lime being often partly replaced by magnesia or protoxide of iron and manganese, and sometimes peroxide of iron and manganese taking the place of the alumina.

Zeolite is a term designating a group or family of minerals,

of which there are twenty-two species enumerated in Nicol's 'Mineralogy.' Of these, analcime, mesotype, stilbite, thomsonite, and chabusite are perhaps those most frequently occurring. They are all silicates of alumina combined with minor and varying quantities of silicate of lime, potash, soda, magnesia, baryta, etc. Their most remarkable character is, that although associated with igneous rocks, they always contain a large proportion of water, so as to boil up under the blowpipe, whence their name of zeolite*. R. Bunsen has shown however, in the Scientific Memoirs for November 1852, that notwithstanding the quantity of water they contain, the zeolites may still have been produced at a red heat. When therefore we find the zeolites generally dispersed through the igneous rocks, or seeming as if they had filled up cavities, it is by no means necessary to suppose that they have been subsequently infiltrated. Their presence may be evidence of a subsequent action on the rock of heat combined with the vapour of water.

For the sake of easy reference the contents of the last few pages are here given in a tabular form, the composition of a fine sort of glass used in laboratories being added, for comparison with the minerals.

* From the Greek word *Zeo*, to boil.

	Silica.	Alumina.	Potash.	Soda.	Lime.	Magnesia.	Lithia.	Iron.	Manganese.	
Quartz	97.5	0.25	...	...	...	...	...	0.5*	...	...
Feldspar. {	Orthoclase	65.35	16.59	...	...	...	...	...	...	...
	Albite	19.13	...	11.62	...	...	...	...	...	...
	Oligoclase	25.86	...	11.77	...	...	...	...	...	...
	Labradorite	29.68	...	4.50	12.13	16.24	...	11.27+	...	...
Horn- blende. {	Hornblende	46.63	...	...	12.63	18.18	...	...	...	...
	Augite	56.36	...	...	25.46	23.70	...	8.16+	...	...
	Diallage	55.22	...	...	9.91	14.00	...	24.50+	...	...
	Hypersthene.	54.25	...	...	1.50	...	...	...	...	...
Mica	Mica	39.80	12.20	...	...	...	5.30	...	...	{ Fluoric Ac. 5.90
	Lepidolite	28.50	8.70	...	...	...	...	5.0*	...	Water 11.5
	Biotite	16.0	7.6	...	...	25.9	...	15.0+	...	...
	Chlorite	21.8	...	...	...	25.5	...	...	...	...
Zcolite	Talc & Steatite	63.9	...	...	...	36.1	...	8.66+	0.25+	{ Boracic Ac. 4.02
	Olivine	41.54	...	...	...	50.04	...	17.44+	1.89+	...
	Tourmaline } & Schorl	35.48	0.48	1.75	...	4.68	...	...	...	...
	Leucite	55.7	21.2	...	...	...	...	5.19+	1.78+	...
Zcolite	Epидote	28.94	...	16.1	20.52	4.75	...	...	...	Water 9.3
	Mesotype	26.6	...	13.9	...	...	...	...	...	Water 8.0
	Analcime	22.9	...	...	...	...	...	...	...	...
	Glass	2.2	11.0	...	10.0	2.3	...	3.9+	0.2+	...

* Peroxide.

+ Protoxide.

On looking over this table, the first thing that strikes us is, that silica is the most essential ingredient of all the minerals, and generally forms at least half of each. This is more especially the case with those minerals which enter most abundantly into the composition of the igneous rocks, as we shall see presently. On comparing the composition of all these minerals with that artificial mineral substance with which we are all acquainted, namely glass, we see so striking an analogy, that it is evident we might look upon all these minerals as glasses, differing in colour, in opacity, in hardness, weight, fusibility, and other properties, according either to the nature of their components, or to the proportions in which they are combined. They are all glass, according to what may be called the abstract idea of glass, namely the union during fusion of silica with some other of the earths and alkalies.

This unity in what may be called the fundamental nature of the igneous rocks, would be equally apparent if we traced their analysis to their ultimate elements. It will be recollected that every one of the substances forming minerals, described at p. 84, are oxides of some kind or other. The proportions *by weight* of oxygen and the other elements are in—

Silica,	24	parts of Oxygen,	22	of Silicon.
Alumina,	24	,,	27	of Aluminium.
Lime,	8	,,	20	of Calcium.
Potash,	8	,,	39	of Potassium.
Soda,	8	,,	23	of Sodium.
Magnesia,	8	,,	12	of Magnesium.
Lithia,	8	,,	6	of Lithium.

If therefore we follow any of the minerals, for instance, a feldspar, a hornblende, and a mica, to their ultimate elements, we have the following results:—

Orthoclase consists of silica, 65·4; alumina, 18; potash, 16·6; but by calculating the quantities of oxygen contained in each of those substances and adding them together, we find that orthoclase consists of a percentage of 43·4 parts of oxygen, 28·9 parts of silicon, 9·8 of aluminium, and 17·6 of potassium.

One analysis of Augite is—silica, 56·36; magnesia, 18·18; lime, 25·46; which gives us 46·3 parts of oxygen, 33·8 parts of silicon, 5·9 of magnesium, and 13·8 of calcium.

Similarly, Mica gives a percentage of oxygen, 45·9; silicon, 21·9; aluminium, 22·4; and potassium, 9·9.

Now, if in these three examples we group the oxygen and silicon together, we shall find that these two substances

compose, of the feldspar, 72 per cent. ; of the augite, 80 per cent. ; of the mica, 68 per cent. very nearly. Accordingly the simple ingredients in which those different minerals differ from each other, only form from 20 to 30 per cent. of their composition, while they are all identical as to 70 or 80 per cent. of their composition.

Another general result may be stated here, namely, that silica and alumina are by far the most abundant substances both in minerals and rocks, and especially in igneous rocks, and that these substances contain much the larger relative amount of oxygen ; while those substances that contain a far less relative amount of oxygen, such as lime, potash, soda, and magnesia, form the minor ingredients of minerals, and the minerals in which they most abound make by far the smaller proportion of rocks, and especially of igneous rocks.

Having seen how certain substances combine to form certain minerals, let us now examine how these minerals combine together to form certain igneous rocks, those namely which enter most largely and conspicuously into the structure of the crust of the earth. Of these, Granite is the principal.

GRANITE is composed of quartz, feldspar, and mica, the feldspar being commonly either orthoclase or albite. The three minerals are confusedly crystallized together and entangled one with the other, the feldspar being generally the one assuming the most regular and perfect crystalline form; the feldspar is also usually the most abundant mineral, the proportions being often stated as three of feldspar, two of quartz, and one of mica.

The relative abundance of the minerals however, and their state of crystallization, varies indefinitely, not only in granites in different localities, but sometimes in different parts of the same mass of granite. When these variations become extreme, it is sometimes advisable to describe them by different names, whether the variety arise from the substitution of one mineral for another, or merely from a change of state in one or all of the ingredients. When the mica goes out and the other two minerals become blended into a fine-grained rock, almost compact, it is sometimes called Eurite. When talc takes the place of the common mica, the rock is called Protogine. When the mica disappears, and only quartz and feldspar are left and arranged in a certain way, we have Pegmatite or Graphic granite. When the feldspar is of the variety called Andesin, and the rock

contains hornblende, some mica, and a little quartz, it is called Andesite: this is the granite, or one of the granitic rocks, of the Andes.

Many granites, in addition to the three first-mentioned minerals, also contain hornblende, sometimes in as much abundance as the mica. Sometimes moreover the mica disappears altogether from this rock, leaving a crystalline compound of quartz, feldspar, and hornblende, which is then called Syenite. This word is derived from Syene in Egypt, where however the syenite sometimes contains mica, so that it is difficult to distinguish it from true granite*. Similarly in Leicestershire and many other places, the rock, although mineralogically a syenite, from its containing hornblende and no mica, is geologically a true granite.

If we look upon granite as essentially a feldspathic rock, and suppose it deprived of both mica and hornblende, and then reduced to a non-crystalline paste, we should have a rock which is very abundant in some regions, but which, from its very defect of all structural peculiarities, it is difficult to describe. Compact feldspar, feldstein, petrosilex, cornean, hornstone, porcelain trap or porcellanite, are all names

* See a paper by M. Delesse in the Journal of the Geological Society of London.

that seem to have been applied to rocks of this sort. They all appear to be some kind of feldspar, containing more or less silica mingled with it, neither the one mineral nor the other having separated or crystallized out from the other. The only convenient general term for these rocks appears to be that of "feldspathic trap." Large masses of these rocks in North Wales exhibit no internal structure, except an occasional flakiness, the whole rock being white or grey, with a green translucent tinge at the edges.

Sometimes however, in a mass of rock having this uniform and compact texture, we might discern here and there a more or less perfectly formed crystal, generally of feldspar, but sometimes of quartz, and occasionally these disseminated crystals become pretty numerous: when that is the case the rock is called a "porphyry." This word originally signified "purple," but it has come now to have a purely technical meaning among geologists, any rock being a "porphyry" or "porphyritic," which has either crystals disseminated at intervals in a compact base, or has large crystals disseminated through a more finely crystalline base. We have in this way porphyritic granite, feldspar porphyry, greenstone porphyry, etc.

From the feldspathic traps the transition is an easy one

to the feldspathic lavas ; of these the most characteristic variety is—

Traehyte, a rough, grey lava, almost entirely composed of crystals of glassy feldspar in a base of the same.

Traehytic porphyry, a very abundant rock in some volcanic regions, contains crystals of quartz imbedded in, and disseminated through, the traehyte. It therefore approximates very nearly to granite in its constitution.

Domite is a more earthy variety of traehyte.

Phonolite, or elinkstone, and claystone, are feldspathic volcanic rocks, though some of them can hardly be distinguished in hand-specimens from the feldspathic traps mentioned before.

Pumice is trachyte in a light spongy form.

Pearlstone, a feldspathic rock, with a pearly lustre, often nodular.

Pitchstone, a dark rock, with pitch-like aspect, passing into

Obsidian, which is volcanic glass, varying in composition, just in the same way that artificial glass varies, and composed for the most part of similar ingredients.

Greystone is a feldspathic lava, containing some augite, and therefore intermediate between the feldspathic lavas and those afterwards to be described.

GREENSTONE.—This is composed of feldspar and hornblende, the two minerals being distinctly crystallized, and the crystals confusedly intermingled and attached one to the other. In ordinary greenstone the feldspar is orthoclase or potash feldspar, and the hornblendic mineral is common hornblende, and not augite.

Now if we imagine a rock which on cooling down contained more than sufficient silica to compose those two minerals, and the overplus to crystallize out in the shape of quartz, we get a granular mixture of quartz, feldspar, and hornblende, or in other words syenite. In this way greenstone passes into syenite on the one hand, while granite passes into it on the other, by the replacement of its mica by hornblende. Syenite is therefore the middle term, or transition rock, between granite and greenstone.

Diorite is a greenstone composed of hornblende and albite, or soda feldspar.

Dolerite is a greenstone in which the feldspar is labradorite (lime feldspar) and the hornblendic mineral is augite.

Euphotide is a greenstone in which the hornblendic mineral is diallage, and the feldspar labradorite.

Hypersthene rock is a greenstone in which the hornblendic mineral is hypersthene, and the feldspar labradorite.

Besides these we have hornblende rock and augite rock, in which those two minerals are present almost alone, with scarcely any feldspar of any sort*.

Basalt.—The passage from some kinds of greenstone into basalt is almost imperceptible. The only distinction indeed in their mineral composition appears to be that true basalt always contains olivine and magnetic iron, in addition to either hornblende and orthoclase, or augite and labradorite. Basalt is always a very fine-grained, nearly black rock, in which the crystals are only discernible with a lens.

From basalt (often the product of volcanoes) we pass directly to a set of lavas differing from it rather in structure than in composition. We have sometimes a close, heavy, compact stone, with no crystals, which is sometimes called *Wackè*. We have also dark stones full of vesicles (porous lava), and those vesicles and the surface of the stone glazed as it were like a slag; and finally, actual cinders and ashes.

With respect to all of these rocks that we can imagine to have been produced, or to have taken their present form

* I have omitted Serpentine from this enumeration, because that term is sometimes applied to a simple mineral, sometimes to an igneous rock, and sometimes to an altered limestone. In all cases magnesia is a principal ingredient of it, and, as a simple mineral, it is a silicate of magnesia, with protoxide of iron and water.

above ground, whether under air or water, they may each have their accompanying ashes. This is true of the feldspathic traps and the greenstones, as well as of the feldspathic and hornblendic lavas. It is almost impossible to describe these ashes; their characteristics and their nature can only be learnt from study in the field. I believe however that it is possible, even in hand-specimens, to distinguish (if the observer be well and freshly practised) between the ashes of feldspar trap* and those of greenstone and basalt. Those who have studied volcanoes can doubtless distinguish as easily between the ashes of the trachytic and hornblendic lavas, or, as some geologists describe them, between tuff and peperino.

From what has preceded, it appears that all igneous rocks admit of being roughly classified under two great divisions, the Feldspathic and the Hornblendic rocks; the two however being linked together by some rocks uniting both characters. We have seen also that in each series

* It is often very difficult to distinguish between feldspar trap and feldspathic trappean ash, and it can then only be done by studying, in the field, the relations of the igneous rock to the aqueous ones with which it is associated, or by tracing the "ash" to a place where it contains small angular fragments of other rock, thus proving its mechanical origin.

there was a regular gradation from granite to recent lava ; on the one hand through feldspar-trap into trachyte and obsidian, on the other through syenite into greenstone, and thence into basalt and scoriaceous lava.

As a matter of convenience, it is often useful to have a term to distinguish between those rocks which are neither granite or granitic on the one hand, nor lava or volcanic on the other. The term that appears best adapted for this purpose, on account of the vague and general way in which it has commonly been used, is the word "Trap." This word was formerly used to designate only a certain set of the rocks just mentioned. In Swedish, *trappa* means *a stair* ; and some *hornblendic* igneous rocks were called Trap, because they assumed a certain step-like form on the hill-sides. It is however quite competent to us to dismiss (as in the case of porphyry) the original derivation of the word altogether from our minds, and to use the term Trap, in a purely technical sense, simply as a combination of letters as good as any other for our purpose. If this use of the term be allowed us, we can throw the igneous rocks before described into the following tabular form :—

IGNEOUS OR UNSTRATIFIED ROCKS.

GRANITIC		Granite, Eurite, Protogine, Pegmatite, Syenite.
TRAPPEAN.	Feldspathic.	{ Felstone, Compact Feldspar, Feldstein, Petrosilex, Cornean, Hornstone, Porcelain Trap, Trappean Ash.
	Hornblendic.	{ Syenite, Greenstone, Diorite, Dolerite, Euphotide, Hypersthene rock, Augite rock, Hornblende rock, Basalt, Trappean Ash.
VOLCANIC.	Feldspathic.	{ Trachyte, Domite, Pumice, Phonolite or Clinkstone, Claystone, Pearlstone, Pitchstone, Obsidian, Tuff, Ash.
	Intermediate.	Greystone.
	Hornblendic.	{ Basalt, Wackè, Compact and Porous Lava, Scoriæ, Peperino, Ash.

The reader must not imagine that all the igneous rocks are included in the above list. It only pretends to give those which have the most marked characters and are of the most frequent and general occurrence. Several other varieties might have been mentioned, which have a sufficient individuality to allow of description and designation by a distinctive name. Besides these, however, there occur in nature large masses of rock, in which the mineral matter is so blended and mixed, that it is impossible to say exactly of what simple minerals they are composed. Chemical analysis would enable us to give a guess at the minerals composing the actual piece of rock analysed, but different

portions of the same mass of rock would give different analyses, leading sometimes to widely different results. One part of such rock might seem to belong rather to the feldspathic, another to the hornblendic series. Even where the rock has distinctly recognizable characters, this blending may take place. That which is granite at the centre may be greenstone on the outside, with or without an intermediate portion of syenite.

Having now described the composition of the igneous rocks, we must briefly mention some of the more remarkable structures exhibited by them, whether internal or external.

Of internal structures crystallization itself might be mentioned as one, but that has already been sufficiently described, as also that peculiar modification of crystalline structure called porphyritic. In some basaltic rocks, as for instance at the Giant's Causeway, there is another structure, resembling this, called amygdaloidal, or almond-like. Round or almond-shaped, crystalline, often radiated and fibrous, mineral substances are seen imbedded here and there in the basalt; these are generally some kind of zeolite. They look often as if they had been subsequently infiltrated into holes and cavities of the basalt, and when zeolite they formerly

were presumed to have been so, but it is now thought that they have separately crystallized from the rest of the mass as it cooled, just as chalk flints and balls of iron pyrites segregated themselves from chalk before it consolidated. In some rocks certainly fibrous zeolitic-looking minerals are so dispersed and entangled with the rest of the mass that they must be contemporaneous with it, and therefore it appears probable they are likewise so in amygdaloids.

In some trap rocks, especially in some feldspar traps, a nodular and concretionary structure sometimes prevails. In North Wales some of these traps become in places a mass of nodules, the size of the fist, lying quite close together; when broken open they frequently appear not to differ from the rest of the rock, but sometimes they are hollow, containing green earth or crystals of quartz with a concentric coating, resembling some agates. Other feldspar traps again exhibit a wavy banded and lined structure, resembling the bands or streaks of different colour and texture often seen in slags from an iron or glass furnace.

One of the most remarkable structures characteristic of the igneous rocks, is that which is best developed in the basaltic and hornblendic class, but which is often more or less distinctly observable in the feldspathic and granitic.

This is their tendency to form spheroidal blocks with concentric coats,—a structure that, when fully carried out, produces jointed columns.

In granite this spheroidal structure only becomes perceptible in blocks that have been for ages exposed to the weather; these blocks are almost invariably found to have assumed a rounded outline, and a sharp blow will sometimes detach a complete shell of half-decomposed matter from them, leaving a fresh surface underneath. It is this structure which has caused the cheese-wrings, logging or roeking stones, and other supposed Druidical remains in granitic countries*.

In greenstone and basalt, especially the latter, this structure is still more prominent. If any one would take one of the angular hexagonal blocks of the Giant's Causeway or other basaltic mass, choosing one that is a good deal weathered, and break off the corners with a hammer, he would frequently see coat within coat in the interior of the block, the external ones squeezed flat towards the sides,

* These artificial-looking masses, together with the supposed sacrificial basins, or regular hollows worn in granite, may be as often seen in the granite of Newfoundland or of the north-east coast of Australia (to speak of places within my own knowledge) as in Devon and Cornwall.

but the internal ones becoming more and more circular, till the last one is found to envelope a solid spheroid like a cannon-ball.

The way in which this globular or spheriodal structure is developed, was discovered and described in 1804 by Watt, who experimented on a mass of basalt from the Rowley Hills, near Birmingham. These experiments have often been repeated, and I have seen the results of similar ones made at the Birmingham Philosophical Institution.

A mass of basalt was melted in a furnace. When melted, a ladle-full of it being taken out and cooled rapidly, formed a dark glass, in fact obsidian. When cooled more slowly, little globules were formed throughout the mass, which then resembled a pitchstone. Suffered to go on a little further, these globules disappeared, and the mass became more stony than glassy. When cooled much more slowly, it assumed a perfectly stony texture, and returned to its original condition of basalt, but there then became apparent in it a structure which may be described in the following way. Small points developed themselves here and there in the mass, from which a few fibres or lines radiated like a star. Round these points as centres, small spheroidal planes of division formed, dividing the fibres into a set of con-

centric coats. These continued to increase in magnitude, or rather they became developed one outside the other, until the coats of two neighbouring balls touched each other. As this was going on, the inner ones disappeared again, and the central nucleus became solid. When the external coats of two neighbouring spheroids touched each other, they did not coalesce, but mutually compressed each other. If the cooling be still longer delayed, the compact stony texture changes into a crystalline one, the whole becoming a granular congeries of crystals.

Now if we have a layer of balls of equal size, all touching each other, each ball is touched by six others at equidistant points all round. This will be seen by looking at the circles

Fig. 1.

marked A, B, in Fig. 1. If the balls were compressible, and were acted on by a lateral compressing force equal

in every direction, or, which comes to the same thing, if they all equally expanded and mutually compressed each other, so that no space was left unoccupied, it is clear that every ball would be squeezed into a hexagonal pillar or prism, as shown by the lines in the figure drawn between the circles. If there were several layers of balls one over the other, and the compressing force acted laterally while the mass was restrained from bulging either at top or bottom, the whole would be squeezed into hexagonal prisms, articulated at regular intervals, the articulations being sometimes flat, sometimes having a cup-and-ball structure, according as one ball impressed or was impressed by the one above and below it.

If this spheroidal structure were left to act alone, there would be no reason why the balls should be arranged in rows, each ball exactly over another, so as to produce a series of long columns. There is however here another structure that comes into play, more or less common to both igneous and aqueous rocks, but most conspicuous in the former, and this is "jointing." In the case of igneous rocks, as they pass from a fluid to a solid state, or become consolidated, they are split into blocks of various shapes and dimensions, by planes running in various directions. In the case of basaltic rocks, these planes seem to spring

from the surfaces of the mass (bed, dyke, or vein, as it may be), where the cooling first takes place, and to strike into the interior in such a way as to form long columns or prisms of rather irregular shape and size. It would appear that this action, occurring simultaneously with the formation of the spheroidal structure, gives the spheroids a tendency to arrangement in rows, each sphere commencing in the centre of the jointed prism; and that when perfectly carried out, this union of forces produces the beautifully regular hexagonal columns (often with cup-and-ball articulations) that we find at the Giant's Causeway, Staffa, and other places.

We have already spoken of "joints" in describing the structure of the aqueous rocks, but in igneous rocks this jointed structure is more perfectly carried out, and forms indeed the only planes of division which traverse them, and prevent them from being one solid and utterly intractable mass. Three sets of planes are necessary for this purpose*. All those of one set usually run more or less parallel to each other, and more or less nearly at right angles to the other two sets. For instance, one set may be horizontal, another

* For "joints" in aqueous rocks, see Plate XI.; for those in granite, see Plate XVI.

set vertical running north and south, and the third vertical running east and west. It often happens, especially in granite, that these joints are so perfect over such large spaces, that the mass assumes a very stratified appearance; this is particularly the case if one set be nearly horizontal or slightly inclined, as they strike the eye like beds in a limestone or sandstone quarry. Besides these joints, which are regular and parallel over considerable spaces, others often occur quite irregular, running in various directions, and inclined at various angles to the horizon.

A question may here be asked, perhaps, which we ought to endeavour to answer, namely, How came minerals and rocks in a state of fusion? in other words, What is the cause or the origin of a heat sufficient to melt the most refractory rocks, to heap up and pour forth floods of melted stone, to pile up great mountain-masses out of the mere dust and refuse of its safety-valves, and to shake and lift up whole continents at once?

In the last chapter we briefly described the extent to which-volcanoes were spread over the globe, and the similarity, not to say identity, of their effects and products in all latitudes. If we were to examine the other igneous rocks, the trappean and granitic, we should find an equal

identity throughout the globe. Granite is granite everywhere, throughout America, throughout Europe and Asia, at the Cape of Good Hope, throughout Australia, in the Indian Archipelago. The same may be said of greenstone and basalt, feldspar-trap and porphyry; they occur and have the same general characteristics over the whole globe. This heat then, whether in ancient or modern times, whether in its superficial or most deep-seated manifestations, has been everywhere the same, and everywhere produced the same effects. This statement at once precludes the possibility of its arising from any partial or local cause; it must be deep-seated and common to the whole globe. Two methods of accounting for it are alone open to us:—

The metallic bases of the earths and alkalies, such as silicon, aluminium, sodium, potassium, etc., etc., when oxygen (whether it be derived from air or water) gains access to them at a proper temperature, unite with it so fiercely, as to produce vivid combustion and generate great heat. It is supposed therefore that these metallic bases exist in large quantities in the interior of the globe, and that they are continually combining with oxygen somewhere or other, and this combustion taking place on a grand scale. This hypothesis is one that is sufficient to account for

the facts of individual cases, and may perhaps be so modified as to account for the similarity in the igneous rocks over the whole globe. Objections that were raised to it on purely chemical grounds, have since been shown to be untenable*.

The other supposition is that the earth was originally, or at one period of its history, entirely in a fluid state, a globe of molten matter; that a cooled crust then formed on it, which would at first be formed entirely of igneous rocks; that after water had been formed and had existed for some time on it, the aqueous rocks were commenced, but that the molten matter of the interior occasionally forces its way to the surface, either along great cracks or at weak spots, and that, in its uneasy throes and pulsations, it has formerly, and still does occasionally, squeeze or inject yet molten matter into parts of the cooled external crust.

A modification of the latter hypothesis is supported by some (partly on astronomical grounds and considerations of general physics), namely that whether the earth was ever entirely fluid or not, its interior is not now so, but that great subterranean lakes of molten matter exist in the inte-

* See Bunsen's paper "On the Igneous Rocks of Iceland," Scientific Memoirs, Part I., Nov. 1852.

rior at no great comparative depth in the earth, and not sufficiently extensive to at all resemble a central fluid nucleus.

Under the latter hypothesis or its modification, the essential unity of the igneous rocks is fully allowed for and accounted for. We have seen in this chapter how intimately connected they all are, how they graduate and pass into each other, how even they are all composed of the same substance, Silica, for at least half their mass, and how few are the other ingredients essential to their existence. The hypothesis of original fluidity accounts in the fullest way for their sameness in all parts of the globe, and for the similarity of the composition of even their most striking varieties. Accepting it, we should view them all as springing from the same mass of matter, their varieties resulting either from substances added to their composition in their passage towards the surface, from the re-arrangement of their constituents in various parts according to accidents not known to us, or from the different conditions to which they have been subjected, as to pressure, rate of cooling, or subsequent alteration.

It has been well remarked by Professor John Phillips, that the two hypotheses are not incompatible, and may be both entertained and united.

If we chose to speculate on such matters, we might suppose that at one time the surface of the earth, or even a greater part of it, was composed of the metallic bases of the earths and alkalies; in which case the first introduction of oxygen would convert it into a fiery globe, that would ultimately have a cooled surface entirely composed of igneous rocks. Many other speculations might be formed; but however amusing may be the occupation, it is not scientific, and we will therefore no longer continue it.

We shall however see it necessary to conclude that Igneous rocks, as a class, were formed before any Aqueous rocks existed, although we must not imagine that any of those primitive igneous rocks can be now exposed anywhere to our observation; even if any of them still exist in their original form and condition.

CHAPTER VI.

THAT SOME AQUEOUS ROCKS HAVE BEEN GREATLY ALTERED BY HEAT, AND ARE THEREFORE CALLED METAMORPHIC OR TRANSFORMED ROCKS,—AND ON THE STRUCTURE OF THOSE ROCKS.

IN Chapter IV. something was said of igneous rocks having altered what they came in contact with,—of their having made chalk into marble, soft shale into a hard jasper-like stone, coal into a substance resembling coke, and so on.

In the early days of Geology, when the nature of igneous rocks was the subject of a violent dispute (the controversy, like all others, being so much the hotter from many of the disputants having very little real knowledge of what they were quarrelling about), one of the arguments brought forward to prove that the basalt of the Giant's Causeway was really of igneous origin, was that the chalk on each side of the

basaltic "dykes" was converted into crystalline marble. The Neptunians, as they were called, laughed at this, for, said they, if you burn chalk you don't convert it into marble, you make it into *lime*. This argument at first sight seemed unanswerable; but it really was founded in ignorance and presumption (like some other arguments we have seen even in our own day about geological matters), for the propounders of it argued from their own limited experience, and did not take into account the possible effect of conditions other than those of a lime-kiln, under which heat could be applied to chalk. Sir James Hall soon turned their argument against themselves by showing that if heat were applied to chalk (or carbonate of lime) under such an amount of pressure as would not allow the escape of the carbonic acid gas, the chalk could be actually melted, and that when suffered to cool gradually under this pressure, it assumed a crystalline structure, and became consequently what we call marble.

Examples of similar alterations in other substances were soon accumulated in abundance, and the igneous origin of a certain set of rocks, and their action on other substances with which they came in contact, became part of the established science of geology.

This action is of course very various. It must vary, first

G. V. D. Noyes, del.

Hubbards & Walton Lith.

CHERT IN MOUNTAIN Limestones, by J. E. S. T. W. W. N. (C. O. G. H. L. C.)

of all, from differences in the nature and mass of the igneous rock, and, secondly, from differences in the mineral character, mode of aggregation and arrangement in the particles of the aqueous rock near it, or other circumstances.

If the mass of the intruded igneous rock be small, it of course will cool more rapidly, and therefore cannot impart so much heat to the surrounding rocks as if the mass were larger. If the kind of aqueous rock into which the igneous matter is intruded be one not easily acted on by heat, it will of course not be so greatly affected as another rock which is more easily altered by heat.

In one case a great mass of molten rock may suddenly be brought into contact with an aqueous one, and its heat may be so intense that it may require a great period of time to cool, during all which time heat is being given off into the surrounding rock, which may itself be easily acted on, and may also be a good conductor, so as to transmit the heat a long way from the surface of the igneous rock. Under such circumstances the alteration will reach a maximum. In another case, although easily acted on itself, the aqueous rock may not be a good conductor of heat*, and thus the

* The difference in the conducting power of a rock may result either from differences in its mineral composition, or in their mode of aggregation

alteration may be great near the surface of the igneous rock, but not extend far into the surrounding rock. Or again the aqueous rock nearest to the igneous matter may be a good conductor of heat, although itself very little affected by it, in which case the amount of alteration may be greater at some distance from the surface of the igneous rock, than it is near to it. Some mineral substances may, as we have seen, undergo one kind of alteration under one set of conditions, and a totally different one under another set. Some minerals may only yield to an intense heat, whether that heat be applied a long or a short time to them; others may undergo a greater amount of alteration from a moderate heat applied for a long period of time, than they would from a great heat for a short time. Many minerals will be scarcely at all affected by heat when by themselves or in conjunction with some kinds of substances, whereas if they are at all mingled with other kinds, they

and arrangement, or it may result from the greater or less quantity of water contained in the rocks. A perfectly dry rock perhaps rarely exists in nature. Bunsen shows (*Scientific Memoirs*, Part I.) that an intrusive igneous rock must first drive all the water out of the rock it comes in contact with, in the shape of steam or vapour, before it can effect much alteration in the rock. This hot vapour or steam however may be itself the cause of some alteration or modification of mineral structure in the rocks it passes through.

will be easily altered by heat. Let us suppose, for instance, that a mass of molten matter comes in contact with a rock consisting almost entirely of pure silica: such a rock might become red-hot and cool again without being much altered; but if beyond it were another rock consisting of silica mingled with some alkali or other flux, the heat transmitted to it might be sufficient absolutely to fuse it, and it might cool down into a crystalline compound, totally altered from its original structure. We must therefore be prepared to find every variety of alteration in the metamorphic rocks, from simple induration up to an entire change of mineral structure.

In order fully to understand what may be the possible amount and extent of alteration that may be produced in aqueous rocks, subsequently to their formation, by the approach of a mass of igneous rock into their immediate neighbourhood, we must for a moment glance back at the origin of aqueous rocks.

The reader will recollect that aqueous or stratified rocks were divided into two great classes, the mechanically formed and the chemically formed. Of the latter class limestone is the only abundant rock, and of all the aqueous rocks we are acquainted with, by far the largest portion, both in extent

and thickness, have been mechanically formed. Speaking roughly, we may say that all aqueous rocks (except limestone) are the result of the wear and tear of previously existing rocks; but if *all* aqueous rocks were thus formed, those rocks which previously existed must have been igneous, since there is no other class of rocks than those two. It follows then that before any aqueous rocks were formed, the surface of the globe was entirely composed of igneous rocks. It follows also that all the aqueous mechanically formed rocks are really composed of materials that once were igneous,—in other words, were once molten by heat. Now if they have once been molten by heat, it is clearly not impossible that if the requisite heat were applied they might be melted again.

It is true that it is also possible that these materials, while acted upon by water, may have undergone such a sifting and sorting, that we may now find in one place only those of one kind, and that that kind may require the presence and admixture of another kind, to act as a flux, in order that the same degree of heat may melt them now that held them formerly fluid. This however is not likely to be always or even generally the case; and for the most part we must believe that if the requisite heat, under the

proper pressure, and for the adequate time, were applied to any mass of aqueous rock, it would ultimately be melted down and reabsorbed into the igneous rocks. If any of these conditions of heat, pressure, or time failed, or if they were all imperfect, the amount of alteration would be likewise imperfect; the effect might go so far as partial fusion, or it might only result in baking or hardening the rocks to a greater or less degree.

Now, as a matter of fact, there are instances of great changes taking place not only in the hardness, but in the mineral structure of certain aqueous rocks, according as they approach the mass of an igneous rock which has intruded into them. Sandstones are found to be hardened into "quartz rocks;" soft shales converted into "mica schist," sandy shales and sandstones into "gneiss." We come then to look upon these rocks and other similar ones as essentially *altered* rocks, and Geologists have therefore given to them the Greek term Metamorphic, or transformed rocks*. I will briefly describe now their principal varieties.

GNEISS.—This rock, like granite, is composed of quartz,

* Although I designedly abstain from referring to many authorities in this little work, it would be injustice to pass by the great class of the Metamorphic rocks without saying that Sir C. Lyell was the first systematic propounder of these views, and the first who fairly reasoned them out.

feldspar, and mica, but those minerals are not, as in granite, confusedly crystalline in all directions, forming a solid connected mass, but are arranged in layers, or thin plates, splitting along a certain given direction. It looks as if a stratified or aqueous rock, containing the materials of quartz, feldspar, and mica, had been so acted on by heat as to allow the minerals to form, but at the same time only to separate a little way one from the other, each kind forming a thin plate or layer to itself.

MICA SLATE or SCHIST.—This is just such a rock as gneiss, splitting into layers or foliating, but composed principally or altogether of plates of mica and quartz, or sometimes of mica only.

Chlorite Slate, Hornblende Slate, or Chloritic and Hornblendic Schist, etc., etc.—These resemble mica-schist except that they are made of the minerals chlorite or hornblende, instead of mica.

QUARTZ ROCK*.—Any one who will examine a piece of quartz rock with a lens will see at once that it looks like a sandstone, the grains of which have been slightly fused or

* The reader must be on his guard against confounding the term "quartz rock" and "quartz." "Quartz rock," or "quartzite" as it is sometimes called, is an altered sandstone; what Quartz is we have already seen.

melted together at their surfaces. Artificial quartz rock may be seen not unfrequently near iron-furnaces. In South Staffordshire, for instance, a rather soft sandstone, got out of the coal-measures there, is used for the bottom of the hearths of iron-furnaces, and after standing the intense heat for some time, splits and is obliged to be removed. The great blocks, called "bears," thus cast aside, may be seen near the furnaces and compared with the unused sandstone, when they will be found to have been converted into a substance exactly resembling quartz rock.

PRIMARY LIMESTONE.—Instead of Primary this ought to be simply called Altered Limestone. It is always highly crystalline, generally has lost all appearance of bedding, and is a granular crystalline carbonate of lime, more or less coloured and marked by various mineral matters. If the limestone were magnesian, or if certain igneous rocks containing magnesia came in contact with the limestone, it would be probably altered into one kind of serpentine.

Besides these rocks, which are commonly considered metamorphic (aqueous rocks altered by heat), there are doubtless others which have suffered metamorphic action so extreme that it is not easily recognizable.

If we suppose a quantity of volcanic rocks, consisting of

various lavas, and various tuffs or ashes, more or less interstratified perhaps with aqueous rocks, to be subsequently covered up and buried under a great accumulation of other rocks, and then to be brought within the influence of a high temperature, it is clear that very great alteration may be produced not only in the aqueous but still more in the igneous rocks. Beds of compact or scoriaceous lava might be remelted and changed into highly crystalline rocks. Beds of ash or tuff might be partially fused into compact trap, or by a still further process converted into porphyritic trap. We have only to think of the very complicated products that must often be produced near submarine volcanic vents, or where subaerial volcanoes eject either their lava-streams or their ashes, etc., into the sea; how purely igneous materials of various descriptions may be mixed in all sorts of proportions with all kinds of mechanically or chemically formed aqueous materials,—to perceive the varied results that may be found, when rocks so formed become subsequently exposed to high temperatures of varying intensity, and under different circumstances. In such cases we must be prepared to find a metamorphic action of a kind only to be unravelled and understood by a long series of the most detailed and accurate observations. Such observations

have as yet been only partially made or published, and if we possessed them they would not be adapted for our present purpose.

In speaking of gneiss and mica-schist we have seen that they had a tendency to split, foliate, or cleave in a certain given direction. Mr. Darwin proposes to give the term "foliation" to this tendency in rocks such as gneiss and mica-schist, confining "cleavage" to that tendency in rocks such as clay-slate. By *foliation* he would understand *the layers or plates of different mineralogical nature* of which most metamorphic schists are composed; by *cleavage*, the planes of division which render fissile a rock appearing to be all of *one mineralogical nature*. We shall see that the two are in reality intimately connected.

Cleavage is a tendency to split in certain directions which is exhibited not only in rocks that are absolutely metamorphic, but also in others which do not appear to have been much, if at all, altered from their original condition, except by this cleavage and by that amount of induration which is common to the majority of all rocks whatever. It is by no means certain, perhaps not even probable, that cleavage is the result of heat; still whatever it arose from, it is a metamorphism or transformation, *pro*

tanto, of the original rock, and its description therefore comes naturally into this division of our subject.

Cleavage is that structure which produces true slate, and is therefore often called slaty cleavage. In some districts (as for instance in the south of Ireland) it affects all kinds of aqueous rocks, hard thick limestones* and coarse sandstones, as well as fine-grained clayey or argillaceous rocks. In some districts also, as in North Wales, it affects some igneous rocks, as for instance fine-grained feldspathic trap. It is however always best developed and for the most part is only to be distinguished in very fine-grained argillaceous rocks, which it converts into clay-slate.

The reader will recollect that in describing shale I spoke of it as an indurated clay that split into thin laminæ; and we saw that these laminæ were "laminæ of deposition," that the rock was formed by film after film of fine sediment having been deposited one upon the other, and that, although partially indurated and compacted together, these films or laminæ preserved a tendency to separate one from the other.

* All the Mountain Limestone of the south of Ireland, as well as all the Old Red Sandstone, is so "cleaved" as often entirely to obliterate the stratification.

This tendency is called "lamination," but technically speaking it is not "cleavage," for cleavage pays no regard to the "laminæ of deposition," or original bedding of the rock, but frequently cuts right across it. Not only does it pay no regard to it, but in cleaved rocks the original laminæ of deposition are commonly, but not always, quite obliterated so far as any tendency to split along them is concerned. They are only to be observed by their different colour or different texture, having been as it were welded together either before the cleavage was produced or more probably simultaneously with it. The beds or strata may be horizontal or variously inclined; they may even be bent, twisted, or contorted, into many curves; the cleavage, on the contrary, is invariably steady in its direction over large spaces, striking in one uniform compass-bearing through great mountain-chains, giving all the fine-grained rocks a tendency to split along its direction into thin planes, and communicating a more or less rudely fissile structure even to the coarser rocks.

Plate XVII. is a view of some rocks in Ringabella Bay, near the mouth of Cork Harbour. The beds "dip" out to sea, being represented by the strong lines inclined at an angle of about 20° , to the right of the picture. The

cleavage-planes are those fine lines cutting across the beds at a high angle to the left. The vertical walls or cliff-sides of the rocks are caused by joints running at right angles to each other, and making the sharp square corners seen all over the rocks.

This superinduced structure of cleavage forms the difference between slate and shale. The word "slate" should only be used to designate subsequently cleaved rocks.

Cleavage, whatever may be its origin, seems sometimes to have exerted a mechanical force not only in splitting the rocks, but in dragging some parts of them some distance along its planes of direction. Nodules of chert imbedded in limestone are sometimes lengthened in the direction of the cleavage (see Plate IX.), and fossils are often distorted and pulled out in the same manner beyond their natural dimensions.

Professor Sedgwick, who was the first to point out the existence of, and to describe, cleavage, long ago, showed that thin films of chlorite or other mineral substance were developed on the surface of the cleavage-planes. It is moreover not uncommon to find not only thin films but thin lenticular-shaped plates of quartz or of a feldspathic-looking mineral developed in the rock parallel to the cleavage-planes.

and across those of stratification. This is evidently the commencement of foliation, which has been before defined as the separation of a rock into thin layers or plates of different mineral substances.

In gneiss there may often be seen alternations of exceedingly thin plates of the three mineral substances, quartz, feldspar, and mica, the plates being wrinkled or corrugated, but all running in the same direction over large spaces. The true stratification, where any such exists, may sometimes, but not always, be detected after much practice, when it will be found that this foliation or separation of the mineral substances into layers pays no regard to it. In many instances this foliation so nearly simulates the lamination of deposition that it requires an observer to be greatly on his guard against accepting it as such.

In mica-schist and other metamorphic rocks the foliation is equally marked, but in micaceous ones it is apt to be exceedingly corrugated or puckered. This waving or wrinkling of the planes is not unfrequently observable to a slight extent in the cleavage-planes of clay-slate, also producing sometimes a regular banding along them, that may at first sight be mistaken for the lines of deposition.

It has already been stated that the cleavage-planes hold

exactly the same direction over great tracts of country. Although their run or direction be the same however, their inclination often varies, as they are sometimes vertical, sometimes inclined one way and sometimes the other. In countries where the beds are much bent or twisted in various directions, it will of course sometimes happen that the planes of bedding will coincide with those of cleavage. I have observed that wherever the direction and inclination of the beds nearly approaches to that of the cleavage, the latter goes a little out of its way as it were in order to coincide exactly with the bedding. In this latter case, smooth flagstones are produced rather than true slate, and I have known the same beds bending over a mountain in North Wales, produce flagstone on one side and slate on the other, according as the cleavage cut across or coincided with their beds.

In passing through beds of different texture moreover, in the same perpendicular cliff, the cleavage may sometimes be seen slightly to change its angle, often becoming more nearly perpendicular in the finer-grained beds. When a very hard coarse-grained gritstone bed intervenes, the cleavage is rarely perceptible in it, giving the rock merely a tendency to split here and there in its direction, and break-

ing it at the upper and lower surfaces into dog-tooth indentations.

The planes of the cleavage generally preserve a pretty high angle of inclination, but I have occasionally seen it as low as 20° . Their direction generally, but not invariably, coincides with the mean direction or “strike” of the beds, paying no regard to the minor undulations. Where the undulations are on a very large scale,—where, for instance, beds in a run of twenty or thirty miles gradually curve round from north and south to east and west,—the cleavage in some cases follows them with equal regularity*.

In examining the cleavage of a country, we may sometimes find two sets of planes, one crossing the other. Sir H. De la Beche remarks that in the south-east of Ireland the cleavage must be of two ages, for the Old Red Sandstone, itself there traversed by slaty cleavage, contains fragments of slate (or cleaved rock) out of a still older formation (the Lower Silurian), lying in such a way as to show that the fragments had been cleaved before they were enclosed in the upper rock.

In some fine-grained rocks, joints are found so parallel and so close together, that it is difficult to distinguish them

* This is observable in the Berwyn Mountains of North Wales.

from cleavage. Professor Sedgwick gives the following rule:—Joints give no tendency to the rock between them to split in any direction; cleavage gives a tendency to the rock to split *indefinitely* parallel to its direction.

As the indiscriminate use of the terms Cleavage, Lamination, Slate, and Schist, gives rise occasionally to some confusion of words and obscurity of ideas, it might perhaps be best to limit them in the following way.

By Laminæ and Lamination are always signified layers of deposition. Cleavage means the superinduced fissile structure of clay-slate; Foliation that of mica-schist, etc.

The term *Slate* should never be applied either to *shales* or any rocks unaffected by a superinduced cleavage on the one hand, nor to any *foliated rocks* on the other: to the latter the term Schist should always be applied. We should thus always speak of the Lamination of Shale; Cleavage of Slate; Foliation of Schist.

G. H. Meyer, del.

Wilmington, N. C.

JOINTS IN LOWER LIMESTONE, RAILWAY CUTTING, FARMER, NEAR DUBLIN.

CHAPTER VII.

ELEVATION AND DEPRESSION OF LAND.

WE have already, when describing the volcano and the formation of igneous rocks generally, said something of the earthquake. We must now turn our attention a little more particularly to the movement of land, either by convulsion or by a slow and gradual process.

The Earthquake, as every one knows, is a sudden motion or trembling of the ground, of greater or less violence. This motion is generally undulating, the solid earth being thrown into waves like those of the sea, accompanied by vibration, just as if the land were a mere crust over some fluid that was suddenly agitated by a moving power, which at the same time communicated a blow to the solid crust, that sent a quivering tremulous motion throughout it. Great

cracks are sometimes opened in the earth, and, what is of more consequence to our present subject, the relative levels of the land are often permanently altered and displaced.

It might not strike us at first that this relative displacement of the level of the land—in other words, its elevation above or depression beneath its former level—is a matter not very easy to observe or detect, except at the margin of the sea. We have on land no *natural standard* of level, and if any large country were gently lifted up a few yards with such a gradual and equable motion that no shock was communicated, it might easily happen that none of the inhabitants of the country would be aware of the circumstance. The rivers perhaps would run a little faster or become a little shallower, but that might naturally be attributed to other causes than the elevation of the land. For all we should know to the contrary, therefore, if it were not for our railroads and canals and the sea-coast, the very country we inhabit might be slowly altering its levels at the present time, either wholly rising or sinking, or rising at one part and sinking at another. Still less, during the terror and confusion caused by the convulsive shock of an earthquake, or while endeavouring to recover from it and repair the damage caused by it, would it occur to people in

general to observe whether the whole country had been elevated or had subsided a few feet. Any consequences of such a movement, such as either the draining of lakes or their formation or enlargement, might easily, and would naturally, be attributed to local and partial causes ; and without a water level of some kind to act as a standard, it is not easy to see how any one could make any accurate observations on the matter.

The mean level of the sea is indeed the only natural standard of level we have upon the globe. In spite of all the varied action of tides and currents, the mean level of the sea must for all practical purposes be absolutely invariable over the whole earth, because the surface of the sea could not be lowered at any place without the adjoining water rushing in to fill it up again, neither could it be elevated without the water rushing from the elevated part on to the adjoining lower levels. The consequence of this is that if at any part there takes place an alteration of the relative levels of the land and water, if any part of the land that was once washed by the sea be now entirely above it, or any part once entirely above it be now underneath it, it must be the land that has risen or fallen, and not the sea. If the sea were to shrink permanently in one

place, it must have shrunk equally over the whole globe, and every coast in the world must show an equal gain of the land in altitude above it, and *vice versa*.

Now we have instances of the rise of land happening in our own day, within the memory and under the observation of people now living. Of these instances I shall select two, one showing the elevation of land during the convulsive action of an earthquake, whereby it was lifted suddenly several feet above its former level; the other proving its more slow and gradual elevation in a manner perfectly insensible to the inhabitants, but amounting to about three feet in the course of a century. In each case the people of the country attributed the difference of level to the "retreat" of the sea, and not to the elevation of the land.

The first instance the reader will find fully detailed by Captain Fitzroy, in the 'Voyage of the Beagle,' and by Mr. Darwin in his 'Journal' and in his 'Geological Observations on South America.' In the great earthquake which, in the year 1835, utterly ruined the towns of Concepcion and Talcahuano, and shook almost the whole country of Chile, the coast was found to have been elevated to a height varying from two to ten feet. Tracts of shore and masses of rock, that had always previously been covered by the

sea, were left dry, and multitudes of marine animals dead and putrefying. Although the total elevation was subsequently somewhat diminished by the country slowly settling down again, still a permanent balance remained. Some facts were observed which rendered it probable that the amount of elevation was greater in the interior of the country than on the coast.

It is interesting to know that at the time this earthquake lifted up and shook the land near Concepcion, a line of volcanoes in the Andes, between three and four hundred miles to the southward, burst into fresh activity, and a volcano burst out at the bottom of the sea adjoining Juan Fernandez, about four hundred miles to the north-westward. A space of ground, measuring at least 800 statute miles by between 400 and 500, or about 360,000 square miles, was therefore at once affected by subterranean forces, causing volcanic eruptions in some parts and violent earthquakes in others.

This instance however was but a solitary step in the great process of elevation going on along the coast of South America. Mr. Darwin shows that by the alteration in the soundings on a bottom of hard rock, the bottom of the Bay of Penco had been raised four fathoms, or twenty-four feet,

since the great earthquake of 1751. He also gives details of observation made both near Concepcion, and at other points of the west coast of South America, showing that lines and beds of sea-shells, and old sea-bottoms, consisting of the powdered remains of sea-urchins, etc., are now found both inland and near the coast, at various heights, varying from 20 feet to 100, to 400, and even to 1000 and 1300 feet above the sea. In all cases the shells were found to be exactly such as now live in the neighbouring seas. At some of the lesser heights, shells like limpets were found still adhering to the rocks, and the shells seemed fresh, retaining their colours; but at the greater heights the shells were worn and weathered; and they were more and more decomposed, and lost more and more of their colour and freshness, in proportion to the height of the deposit above the sea. This shows distinctly that the elevation had taken place at successive steps and at long intervals, those on the greatest heights having been longest exposed to the action of the atmosphere. To any one who had seen as it were before his eyes, the land lifted one step out of the sea, these relics of the sea at various heights upon the land would be the most convincing and irrefutable evidence of the successive step-like elevation of the whole country. He would

have but to let his imagination soar back sufficiently into past time, to see in his mind's eye the whole region thousands of feet lower than it now was, and behold the gradual rising of the mountains from the bosom of the deep by small convulsive starts, which, though individually trifling, yet when accumulated through the lapse of uncounted ages, caused them to swell to their present altitude.

For the other instance we must go to Scandinavia and the shores of the Baltic Sea. The reader will find a most interesting account of this case in chapter xxxi. of Sir C. Lyell's 'Principles of Geology' (eighth edition); all I can do is to lay before him an abstract of that account.

Early in the last century Celsius expressed an opinion that the waters of the Gulf of Bothnia were sinking, because "rocks which were sunken reefs formerly, were in his time above water, ancient ports were converted into inland cities, small islands were joined to the mainland, and old fishing-grounds were deserted as too shallow, some even being dried up."

It was objected that the waters of the Gulf of Bothnia could not sink without those of the southern part of the Baltic suffering an equal depression, but this they had not, because none of the effects were observable there, that

occurred further north. "Moreover several cities of Denmark and North Germany were originally built at the water's edge, and the water remained there now. "The lowest part of Dantzic was no higher than the mean level of the sea in the year 1000, and after eight centuries its relative position remains exactly the same." It was clear therefore that if there had been an alteration in the relative levels of the sand and sea further north, it must have been the land that moved, and not the sea.

Von Buch first of all, and subsequently many other geologists, including Sir C. Lyell himself, have visited the country and investigated the subject, and have become convinced of the fact of the gradual rise of the land over a large tract of country at a rate varying from five feet in a century near the North Cape to only a few inches some distance south of Stockholm. As there are no tides in the Baltic, any alteration of the levels is more easily observable, and marks have been cut in the solid rock, with the dates affixed, indicating the mean level of the sea at the time. These marks were examined in 1820 by the officers of the pilotage establishment of Sweden, who confirmed the fact of the rise of the land, and cut fresh marks at that date. These latter marks Sir C. Lyell examined in 1834, and found that

in certain places near Stockholm the land had risen four or five inches in the fourteen years. From these circumstances, and from the concurrent testimony and accounts of all fishermen and others engaged in constantly traversing the rock- and islet-fringed shores of Sweden and Finland, it appears absolutely certain that those countries are now slowly rising above water, without any shock or disturbance, and so imperceptibly that the inhabitants attribute the effect to the gradual shrinking and subsiding of the sea. Not only does it appear that the rise of land is greater in the north than towards the south, but also that it is greater in the interior of the country than on the coast. That this elevation of the land has been going on for a vast period of time is proved by the fact that great beds of sea-shells are found in various parts of the rising district at various heights up to 400 feet, and at distances from the sea equal in some places to seventy miles. On the ocean side of Sweden these shells were such as are now found living in the North Sea; on the Baltic side of Sweden they differ from these, but agree with the shells now found living in the Baltic. In some places even the barnacles are found sticking to the rocks,—a fact confirmed by Sir C. Lyell himself finding some adhering to a surface of gneiss, one hundred feet above

the sea and two miles north of Uddevalla, "on the partial removal of a mass of shells used largely in the district for making lime and mending roads."

It appears however probable that the movement has not always been one of elevation, but that it may have also at one time been one of depression. "In digging a canal in 1819, at Sodertelje, sixteen miles south of Stockholm, they passed through sixty feet of marine strata, containing Baltic shells, when they came down on what appeared to be an old fishing-hut, in a state of decomposition, with a fireplace, consisting of a ring of stones, within which were cinders and charred wood." Wood cut by an axe was also found with it. Several vessels were also found of very antique form, fastened together by wooden pegs instead of nails. It seems evident, then, that here was once dry land which was subsequently depressed beneath the sea, and the hut and vessels buried under the water, which covered them with accumulations of sea-gravel and shell-marl, the whole being subsequently re-elevated into its present situation.

In the southern extremity of Sweden, namely in Scania, there is not only no elevation now going on, but a permanent depression of the land seems to be taking place. "Lin-næus, with a view of ascertaining whether the waters of the

Baltic were retiring from the Scanian shore, measured, in 1749, the distance between the sea and a large stone near Trelleborg. This same stone was in 1836 a hundred feet nearer the water's edge than in Linnæus's time, or eighty-seven years before." There is also a peat-moss beneath the sea, and, what is still more conclusive, in all the towns of Scania there are streets now below the level of the sea; thus at "Malmö, when the wind is high, the water overflows one of the present streets, and some recent excavations showed an ancient street in the same place eight feet lower."

We have here then distinctive proof of a movement of the land,—elevation at one place, depression at another,—over a tract of about twelve hundred statute miles in length, and between four and five hundred in width.

"On the coast of Greenland it is known that a similar tranquil depression of land is taking place over a space more than six hundred miles long from north to south. Ancient buildings have been submerged, and experience has taught the Greenlander never to build his hut near the water's edge. In one case the Moravian settlers have been obliged more than once to remove inland the poles upon which their large boats were set, and the old poles still remain beneath the water as silent witnesses of the change."

As a very remarkable instance of elevation and depression having alternated in the same spot, I must again refer the reader to Sir C. Lyell's 'Principles of Geology' for an account of the ruins of the so-called Temple of Jupiter Serapis, near Puzzuoli. Of this structure three marble pillars, each of a single block of stone, yet remain erect, springing from a granite floor, which in 1828 was one foot below high-water mark. They were formerly buried to about the height of twelve feet in soft, recently-formed strata of tuff, containing marine shells, which has been excavated around the ruins, but through the bottom of which the sea still soaks. Above this twelve feet occurs a zone of nine feet in height, where the columns are bored in every direction by *Lithodomi*, a marine bivalve shell that bores into and lives in limestone rocks. The floor of the building consequently has been submerged for a long period of time under the sea, to at least a depth of twenty-one feet, and subsequently re-elevated to its present situation, although not to its original height above the sea, as it could not possibly have been built one foot under high-water mark.

These are but a few instances, selected as striking ones, out of the many recorded in Sir C. Lyell's book and other works; the recorded ones in all probability being but a

very slight proportion of those that have actually taken place.

If we searched for evidence of movements of the land having taken place in our own Islands during comparatively recent, although perhaps not in historic times, we should not find them wanting. Raised beaches, as they are called, are frequent on our coasts,—beaches composed of shingles and broken shells such as we now see on the sea-margin, but which are many feet above the reach of the highest possible spring-tides. Evidences of depression are not always equally easy to obtain, because the very fact of depression below the sea removes its evidences from the sphere of our observation. Under the fens of Lincolnshire and Cambridgeshire however evidences of there having once been a surface of dry land, have been met with, where now, if all the peat and bog were removed, there would be a wide-spread sea.

At many points of our coasts also submarine forests are found. These are seen appearing from under the sand at dead low-water mark of spring-tides, and are found to consist of a thick formation of peat full of branches and upright stumps of trees, still in the position of growth, with their roots expanding around them. I may mention, among other places where these submarine forests occur, the shores

of Cheshire between the Mersey and the Dee, where many years ago I dug up at low-water-mark of a spring-tide the upright stump of a tree full of living shells of the genus *Pholas*; the mouth of Youghal Harbour, where my friend Dr. Ball, of Dublin, has seen peat containing trees in the position of growth in the shoals four or five miles from the present coast; and Courtmacsherry Bay, on the coast of Cork, where the people still in some places dig up peat at dead low-water, and I have myself seen the piles of turf drying on the beach. Instances without number might be accumulated, but the reader will find them described in geological books and memoirs, or, still more satisfactorily, may observe them for himself should he ever have the opportunity.

Enough perhaps has now been said to disabuse the reader of the natural idea of the stability of the land, and to prove to him that it is rarely if ever actually motionless over the whole earth at any one time. We have seen that we can actually trace its motion either of elevation or depression in some place or other, through the whole period of the recent historic times down to our own; that it must have been equally going on during more ancient periods is shown by the very fact that all lands known to us are prin-

cipally composed, both in thickness and extent, of rocks that have been formed under the sea, and have therefore been subsequently raised into dry land.

This perhaps will be the best place for noticing that the present shape and form of all our dry lands is the result of the way in which they have been elevated, and have passed through the erosive and destructive action of the surface of the sea. By the form of the land, I mean both the configuration of its coasts and the varied outline of its whole surface.

All lands have been formed either of irregularly shaped masses of igneous rocks, or of great sheets of aqueous rocks. The latter have been variously bent, contorted and broken, by the disturbing agencies to which we have alluded in this chapter. The solid masses having this structure have been slowly raised above the sea, in such a way that every square inch of dry land has been successively exposed to the wearing action of its breakers. By this wearing action, and by the erosive and transporting power of tides and currents, all our present valleys and undulations have been formed.

If the reader will examine any beach composed of soft and yielding materials, at dead low-water, he will see in the form of the sand and mud, in the little branching valleys and

hollows caused by the retreating tide, and the streams of water that follow it from the pools left behind, an exact miniature representation of the forms of a great country, with its basins of drainage, and its branching systems of rivers, streams, rivulets, and lakes.

Every valley and hollow, every slope of a hill, every cliff, every ravine, has been formed mainly by the action of the sea, when that portion of the land was at or but a little below its surface. It may have subsequently been modified by the action of the atmosphere, the frost, or the river, but its principal feature has been formed by the sea. Unless a previously formed valley and system of valleys had existed, the river and its tributaries could not have commenced.

We must of course except from this description those hills which are the result of volcanic eruption or volcanic elevations on the dry land, and such valleys and hollows as may have been caused by similar depressions. These however are such exceptions as, by their obviously distinctive characters to the eye of an observer, serve only to prove the rule*.

If any further proof were wanting than the mere state-

* I recollect, in Java, being struck by the aspect of a small river that seemed to wander over a plain without any distinct valley or any regular bed

G. V. Du Noyer, del.

OLD RED SANDSTONE OF ALBERTA, CANADA, CO. W. EXHIBITION.

Huttmacher & Welter, lith.

ment of the fact of the erosive action of the sea having been the great moulder of the outline of the land, it would be found in the ravines and valleys so often seen crossing the ridge of a great chain of mountains, and commonly called "passes" or "gaps." These could not possibly have been formed by rivers, as there is no place for the rivers to come from unless they ran up-hill. Neither could any other of the minor agencies have produced them. That they are truly eroded, and not the result of any violence or disturbance, is often shown by the beds or rocks on each side of the pass being precisely similar, and evidently once continuous, the lowest bed of all perhaps stretching unbrokenly right across, and forming the floor of the ravine.

It is not often easy to ascertain, or perhaps even to guess at, the circumstances which determined the breakers and the currents to act with greater intensity in one place than another, or to attack one line of country rather than another.

or channel. It had a peculiarly unnatural aspect, for which at the time I could not exactly account. I have no doubt it was a brook, the course of which had been stopped by the action of one of the neighbouring volcanoes, and turned on to a tract that had no valley system prepared for it. It wandered about therefore as a small irregular flood, according as slight variations in the levels of the ground permitted it to flow as a shallow stream or expand into a shallow lake.

This however is to be expected from the very nature of the problem. We can only say that where the rise of the land was comparatively rapid, there the erosive action of the sea would have the less time to act, and the outline of the land consequently be the most smooth and gentle. Where however the elevation was slowest and most gradual, there this destructive power would have the longest time for exerting itself and produce the greatest effect. The grandest cliffs therefore, the deepest and most precipitous ravines, are not necessarily evidences of a period of short and violent disturbance, as might at first appear most probable, or of any "convulsion of nature," to which they are commonly referred by ungeological describers. On the contrary, they are often evidences of a very long continuance of absolute repose in all the disturbing and convulsive powers of nature, and of those gradually-acting, bit-by-bit destructive powers we see every day around us, and are so familiar with as to be regardless of them, having been left to produce their effects undisturbed through an immense period of time.

CHAPTER VIII.

ON THE VARIOUS POSITIONS OF ROCKS, AND THE ACCIDENTS THAT HAVE AFFECTED THEM CONSEQUENT ON THE ACTION OF DISTURBING FORCES. MINERAL VEINS.

IN the last chapter we saw that the solid rocks were subject to a disturbing action, proceeding from the interior of the earth, by which they were raised above or depressed below their former position. This action is sometimes regular and equable, and resulting in a motion insensible in any small portion of time; sometimes impulsive or convulsive, producing very sensible effects in brief periods of time, but often with long intervals of repose between them.

It is obvious that the results of any such force acting as gradually as is here stated (whether by gradually we understand a slow continuous movement, or one acting by very

small steps at a time, and a long interval between each), can only be very large when there has been a very large period of time for them to accumulate in. Any results therefore accumulated during the last few thousand years, can only be of comparatively small importance with reference to the whole surface of the earth or the whole mass of the rocks which are in any way brought within the sphere of our observation. When however we come to examine the rocks composing the crust of the earth, we find evidence of great disturbance and great dislocation, of enormous elevations and depressions, of disturbing forces having acted both vertically and laterally, of beds being not only bent into simple or double curves, but of their having been crumpled up into many and violent folds and contortions, and even of their having been forced back and overturned so as to lie with their under surfaces upwards.

I will now enumerate and describe all the most frequently occurring and most striking of these forms of disturbance. These will come under two heads :—1. Unconformability ; 2. Dislocation.

1. UNCONFORMABILITY.—The reader will recollect that in both kinds of elevation mentioned in the last chapter, the effect was greater in one direction than in the other.

The rocks were believed to be more elevated inland than on the coast, and more at one part of the coast than at another.

In Scandinavia it even appeared that while elevation gradually increased towards the north, it not only ceased towards the south, but was converted into depression. By this action, beds that were once horizontal would be tilted up in one direction, and made to incline downwards, or "dip" as it is called, in the other.

Suppose now, that we have a series of stratified rocks, 1, 2, 3, 4, 5, 6, 7, consisting of regular horizontal beds

Fig. 2.

- formed under the sea, and that these beds are slowly elevated in this manner, and that as they pass through the destructive plane of the sea-level they are all eroded and worn away, and their ends cut off so as to form the new surface A B; that they are again depressed bodily below water, and upon that new surface another set of beds, 8, 9, 10, are formed. Of these two sets of beds, all of each set are said to be conformable to each other; that is, 1, 2, 3, 4, 5, 6, 7

are a set of conformable beds, and so are 8, 9, 10, but the bed 8 is unconformable to all those below it, and the group 8, 9, 10, is unconformable to the group 1, 2, 3, 4, 5, 6, 7.

We must remark here, that by the very terms of the above statement, there is clear proof of a considerable interval having occurred between the formation of the beds 7 and 8, during which interval, instead of any fresh deposition of matter having taken place, the previous deposits were being tilted up and a great portion of them being destroyed and removed. This is the most simple and obvious case of unconformability. To prove unconformability however it is not always absolutely necessary that the lower beds shall be inclined and the upper horizontal, or even that they should be inclined at different angles. Both sets of beds might be horizontal; or inclined, so far as could be judged, at the same angle; still if there were anywhere proof of erosion and denudation having taken place in the lower set before the upper were deposited, we must declare the two unconformable. For instance, the lower set might have small cliffs or hollows in it, or pinnacles rising from it, with the beds of the upper deposited against these unevennesses. This direct unconformability is in almost all cases proof of elevation having taken place, and consequent erosion

and denudation, in the interval of time that elapsed between the formation of the two sets of beds.

There is however another kind unconformability, to which the distinctive name of “overlap” is applied, which is commonly a proof simply of depression having taken place to produce it, though it may not even prove that*.

In Fig. 3, upon the continuous beds 1 1, is seen another set, 2, 3, 4, 5, each overlapping the other in such a way, that while at A they all appear conformable, at B No. 5 rests on No. 1, the other beds having successively thinned out and come to an end. This may possibly have resulted simply from a defect of materials to continue the depositions 2, 3, 4, far enough towards B; but it is more likely, and is more frequently found in nature, to have resulted from the fact of 1 being a much older bed than 2, and from

* I must warn the reader against supposing the woodcut figures are absolute *representations* of nature. They are mere diagrams to assist the written explanation and represent the facts in a succinct and condensed form to the eye, the very fact of condensation rendering absolute portraiture impossible.

its having formed dry land or shallow water between C and B when 2 was formed, and then of continuous and gradual depression below the sea having taken place during the formation of 3, 4, and 5, allowing them to extend successively further towards B, until, during the deposition of No. 5, the sea spread over the whole.

2. DISLOCATION.—Sometimes a set of beds are bent into an arch or into a set of undulating curves, both upwards and downwards. These curves may vary in magnitude from a few yards to many miles. When only a few yards across, they come rather under the head of Contortion, but when of larger scale, they are described in the following terms. A curve with its *convex* side upwards, like a saddle or the roof of a house, or a ridge, is called an *anticlinal* curve; a curve with its *concave* side upwards, like a trough or a furrow, is called a *synclinal* curve. An anticlinal curve may be a dome-shaped protuberance, the beds dipping every way *from* a centre, or having a quaquaversal dip. A synclinal curve may be part of a basin-shaped depression, with the beds dipping every way *to* a centre.

More usually however the curves are arranged with reference to lines rather than points, such a line being called the axis of the curve. A line *from* which the beds slope

downwards on each side, is called an *anticlinal axis* or *anticlinal line*; a line *towards* which the beds slope downwards on each side, is called a *synclinal line* or *axis*. These lines or axes may either be parallel to the horizon, like the ridge-roof of a house, or inclined to it at various angles, like the roof of a house set on the ground and tilted up at one end. The curves too may have every possible variety of flexure, from the most acute angle to the lowest and most gentle sweep. They may also gradually fade or pass away, in one or both directions, from the sharpest flexure into a gentle one, the sides gradually widening and flattening, till the whole beds become level or horizontal.

When a number of curves or folds of the strata take place close together and on a small scale, they are commonly called *contortions*. In much-disturbed countries these contortions may sometimes be seen running for miles along cliffs or other exposures of the rocks, the beds being sometimes bent into the most regular curves, so as to resemble architecture, sometimes being irregularly crumpled together as one might fold and crumple sheets of paper in the hand. Plate XVIII. is an example of highly inclined and contorted strata. In the cliff to the right of the centre the crumpled beds seem to have been pushed laterally and

made to slide as it were into folds over the surface of the other beds. At the left-hand corner a small "fault" is seen to cut off the continuation of the beds.

Faults.—Sometimes the beds are not only bent, but cracked and broken through, and sometimes they are cracked and broken without being bent at all. It perhaps most usually happens that where contorted they are not greatly broken, and where much broken they are not contorted, the disturbing force having been expended in one or the other effect, according to circumstances. When the beds are broken through they are commonly *shifted* or *thrown* on each side of the fracture, the mass of the beds on one side having been lifted up or having slid down from those on the other, or both actions having taken place, and one side having been elevated while the other was depressed. (See Fig. 4.) Such a fracture is called a "*fault*," a term adopted from the language of miners, but bearing a more definite and technical signification among geologists than it commonly has among the men from whom its use is derived.

These fractures, or faults, may sometimes form open fissures of some width, the width varying from the very fact of the fissure not being straight, but undulating, and the undulations or indentations no longer fitting into each

other after the *shifting* of the rocks. This is of course more especially the case in hard rocks. In softer ones it is more usual that most of the projections have been all ground off smooth, so that no open spaces are left in the fissure. Sometimes a fault is a clean cut through the rocks, without any twisting or contortion in the adjacent beds. Sometimes they are variously inclined near the fault, as if they had been bent before they were broken. Sometimes instead of one fissure there are several close together, one great fault being made up of several other smaller ones. A large *downtthrow* fault often takes the form of a number of smaller steps*.

In mining operations, especially in coal-mining, portions of the various beds are often found broken, set on edge, overturned, and jammed and squeezed out of all natural shape and form, in these dislocations.

The positions of faults are as various as their forms; sometimes they are perpendicular, but much more often

* From this circumstance it happens that when tracing the run of a particular bed or set of beds across a country, which has been broken by faults, we often find along the line of one of these faults large fragments of the bed or of the set wedged in the rocks in various positions, fragments, as it were, left behind by the way, when one part of the beds was torn from the other.

they are inclined at various angles to the horizon, usually at a pretty high angle, but sometimes at as low a one as 23° , as at A B in Fig. 4.

Fig. 4.

As a general rule, the fault “hades” (*i. e.* dips or inclines downwards) *under* the downthrow or depressed beds. This is an almost necessary consequence of the action of the disturbing force. If, for instance, in the above diagram the part H were to be lowered vertically downwards, the part G would be left unsupported, and would necessarily fall in. In other words, when such fissure or fault as A B is first formed, if the part corresponding to H is depressed, the part G must be equally depressed, and therefore no shifting of the beds can take place at all on opposite sides of the fault.

On the other hand, if motion be communicated to the two masses, either H may be held fast, and G slide down the inclined plane of the fault; or G being held fast to-

wards B, and the expanding and elevating power acting on the wide base of H, it may be forced upwards like a wedge between G and I, bending them perhaps and tilting them a little, but not raising them bodily from their positions. It is clear also that both actions may take place simultaneously.

It will help us perhaps to understand the nature of "faults" if we consider for a moment what must be the nature of the movements and disturbances caused by an elevating and expanding force acting from within the interior of the globe. Whatever may be the cause of this force, whether simple expansion of rock caused by an accession of heat, or the intrusion of solid or liquid masses acted on by expansive gases, or other still more deeply-seated agencies, the result must first of all be a bulging of the crust of the earth, accompanied both by a vertical compression of some of its parts and by a lateral strain upon, or stretching, of the whole mass affected. Mr. Hopkins has shown in his paper, so well known to all geologists, that this elevatory strain acting over a limited but indefinite district, and on a mass of stratified rocks supposed to be all of nearly the same sort, and of nearly equal tenacity throughout, would result in the production of a number of parallel fissures, commencing each one at some point *below* the sur-

face of the ground, and continued up to the surface; and in another set of fissures at right angles to the first-named. The two sets of fissures might be contemporaneous or not.

This is the simplest form of the problem, which in nature might become complicated by the unequal action of the force at different places, by the inequality in the thickness, tenacity, etc., of the rocks acted on, and by other circumstances.

The ultimate *displacement* of the masses thus separated from each other might be effected either by the continued action of the elevatory force affecting some masses more than the other, slifting them up bodily, or tilting them at one end more than the other; or it might be caused by the cessation and withdrawal of the elevatory force, and the consequent subsidence and settling down of the masses in various directions and positions. It is obvious also that the displacement may be caused partly by one action and partly by the other; the first displacements being either diminished or increased by the subsequent one, according to circumstances. It is also obvious that these paroxysms (so to speak) of elevatory and disturbing force may affect the same district not once only, but several times. In all the subsequent movements, it is almost certain that they

would act again and again along the original lines of fracture, since these would continue to be the lines of least resistance. It is most probable also that in consequence of the positions, directions, and inclinations of these fractures, all the subsequent motions would be of the same kind as the original ones; that a mass once elevated would be still further lifted up, a mass once depressed would be still further thrown down, and not the contrary.

We must therefore always be on our guard, in examining the faults and dislocations of a country, against attributing to one sudden and intense movement an effect that may be equally well the result of one very slow and gradual movement, or a great number of step-like movements occurring at various periods and distributed perhaps through a long duration of time.

There are three principal cases of faulting or dislocation.

1. A mass of rock or country may be entirely enclosed by three or more straight lines of fault, or by a curved line or lines sufficient to surround it; and the mass thus enclosed may be altogether elevated or depressed with regard to the surrounding rock or country. This is probably a very uncommon case.

2. Two faults, more or less nearly at right angles to

each other, meeting at a point, the corner or angle of rock or country included between them is elevated or depressed, with respect to the rock or country outside of them; the amount of "throw" being greatest probably near the intersection of the faults, and diminishing as we proceed along each of them.

There is a modification of this case when we have one great longitudinal fault, which either cuts off one or more cross faults running up to it, or gives rise to one or more branching faults springing out of it (two ways of describing the same thing), both the longitudinal and the cross faults "throwing" up or down in any direction and to any amount, but generally acting most intensely on the corner of country included between them near their points of junction.

3. A single line of fracture or fault. This may be either a simple crack or severance of the beds without any displacement of them; or the beds on one side of the fissure may be "bulged," or bent upwards or downwards, while the other side is held fast; or again one side may perhaps be bulged upwards, while the other is bent downwards. It is obvious that in this case the greatest displacement must take place somewhere near the centre of the fault, which

Hullmandel & Walton Lath

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[illegible]

must die out, and gradually come to an end in both directions. The following rude diagram may perhaps serve to explain this :—

Fig. 5.

Let A B C represent the section of a bed once continuous and horizontal; then let a vertical crack or fault take place in the direction of A C; and let D represent the part bulged upwards on the further side of the fault, while E represents the part bent downwards on this side of the fault.

There is a possible modification of this case, when the bending or bulging on either side of the fault is not a simple curve, but an undulation along the line of the fault, the amount of the throw thus having more than one maximum point; or it may be that the beds on both sides of the fault are undulated along it, so that the undulated beds cross each other at one or more places. In this case the fault (regarded as a displacement) would cease and set in again once or oftener along the line of fracture. Moreover

in the same line of fault the downthrow may by this means change sides, or in other words the fault may in one part of its course throw down in one direction, and in another part in another.

In Fig. 5, if we imagine the beds prolonged towards C, and the part E to rise above A B C, while the part D sinks below it, we shall have a representation of this case.

The case of the "single-lined" fault, in its simplest form, that of a bulging up or down of the beds on one side of the fracture, is probably one of the most frequent occurrence in nature.

When two faults (whether they are "single-lined" faults or two branches of a larger fault) occur near together, and both "throw down" the piece of country between them, they produce a "trough." This "trough" may be looked upon as either produced by one fault or two, according as we regard the actual trough-shaped piece, or follow the faults out to their ultimate result.

According to the rule given at p. 163, of the hade or downward inclination of a fault always being *towards* the downthrow, it is clear that in a "trough" the two faults must decline towards each other, and must ultimately meet somewhere. If they are of equal throw, they must, as the

throw is in opposite directions, counteract and obliterate each other, as it were, coalescing into a mere fissure that traverses the rocks below without displacing them. In Fig. 4, if the faults C D and E F are continued downwards, they will thus meet and counteract each other. I have however discussed this question recently elsewhere, and must refer the reader for it to a Memoir on the Geology of the South Staffordshire Coal-field, in the "Records of the Geological Survey of the United Kingdom."

If the throw of the two faults be not equal, one of them must be looked on as a mere branch of the other. In all cases these "trough faults" are evidence of the fissure having gaped, and swallowed as it were a wedge-shaped piece of the rocks, and then closed again, as far as the included wedge would allow it.

We can now understand something of the causes of the folding and contortions of the solid rocks spoken of at p. 160. They are probably in all cases the result of lateral pressure. Now the elevatory force, when merely the result of expansion by heat, must almost invariably act vertically upwards; the force of gravity resisting that, acts vertically downwards. If however, during the action of the elevating force, masses of intrusive matter, whether fluid or solid, be

forced in among the other rocks ; or if masses of the fractured rocks be set on edge and made to occupy larger lateral spaces than before ; or if, finally, masses be engulfed by open fissures, then,—when the elevatory force ceases and a compressing and depressing force comes into play, causing the rocks to settle back into their original position,—the increased bulk of the rocks, consequent on the newly included masses, will cause this compressing force to exert a lateral pressure on the sides or abutments of the collapsing arch, that may in some cases, especially when the arch gets very low, exercise an enormous force. This lateral compressing and squeezing force may also exhibit the result of its effects at a great distance from the actual cracks or fissures, caused by the elevatory force. This subject might be pursued to still greater length, but probably enough has been said to give a general reader or a beginner an idea of it.

In some great mountain-chains, such as the Alps, for instance, the contortions and disturbances are on the grandest and most astounding scale. Square miles even of rocks are not merely contorted, but absolutely turned over, those beds which were once undermost being now uppermost, and so on.

Mineral Veins.—It sometimes happens, more especially among hard rocks, that the fissures we have spoken of as

faults, are found to have become more or less filled with mineral matter subsequently to their formation. For this to have happened, it is not necessary that these fissures should be really "*faults*," that is, that the rocks should have been *shifted* on either side of them. Many fissures may have been formed without any displacement having taken place beyond the mere crack or severance of the rocks. It has already been said that in hard rocks these fissures would have a greater tendency to remain open than in soft ones, and especially that when a "shift" took place, and the fissure was uneven, irregular hollow spaces would be left in it, in consequence of the broken and uneven surfaces of rock no longer fitting into each other. In these open fissures, different mineral substances have been deposited more or less in a pure state, and often assuming a crystalline form. Quartz is found very abundantly in them, as is also carbonate of lime, fluoate of lime, sulphate of baryta, and other such earthy minerals. Along with these very often occur metallie minerals, ores of copper, tin, lead, zinc, silver, gold, etc. These metals are generally combined either with oxygen, carbon, or sulphur. The fissures thus filled up by subsequently formed minerals are called "*mineral veins*," and are the sources from which all our great supplies of lead, copper, zinc, antimony, manganese, and

silver are derived. Iron is more generally extracted from matters not occurring in *veins*, but in *beds*. Gold is sometimes procured from veins, but more usually from sand, clay, and gravel, which however are the mere waste of previously existing rocks, which were traversed by auriferous veins.

The minerals in a vein are sometimes disposed with much regularity, seams or bands of different minerals occurring in the same order on each side of a vein. It would appear as if a seam of crystals of one sort of mineral were deposited first against the walls of the vein, then upon those another seam on each side, perhaps of a different sort, and so on, till they met in the centre.

Great irregularity however is often found in the mineral contents of veins, and they sometimes contain pebbles or blocks of rock broken from the sides or swept in from above. The metallic ores sometimes occur in regular seams in the vein, sometimes in irregular bunches or strings. They sometimes too spread from the true vein in strings and bunches into the rocks on either side of it. A mineral vein, indeed, is found frequently to vary in the richness of its mineral contents, being sometimes filled with minerals that are worthless, such as quartz, sometimes the valuable metallic ores occupying the whole of it. Sometimes too

the walls of the vein expand; sometimes they contract or even close together, resting against each other, and thus "nipping out" the vein over a certain space. Mineral veins also are found almost invariably to vary in their contents where they pass from one sort of a rock into another, more especially passing from a hard into a soft rock, little valuable material being ever found in the latter.

Mineral veins often cross each other, and in this case one is often found to be newer than the other, inasmuch as the one breaks through the other, and "shifts" it, just as a fault does a bed. Where two mineral veins intersect are often found the richest bunches of ore. Among miners a vein is called a "lode;" the principal set of veins are called "lodes," the others being called "cross courses."

The exact method by which these minerals have been deposited in the veins has not yet been fully discovered. Deposition from chemical solution is the most obvious source of them, the water percolating through the adjacent rocks having gathered the elements of the minerals from them, and deposited them in the veins. Mr. W. Fox has shown that electro-galvanic currents still traverse some mineral veins; and electric agency is a probable assistant in the deposition of the minerals where we now find them.

CHAPTER IX.

ON GEOLOGICAL TIME, AND THE CHRONOLOGICAL
CLASSIFICATION OF ROCKS.

IN commencing this chapter I must entreat the reader to whom the subject of Geology is new, to divest himself of all preconceived notions as to the age of the world. I shall not ask him in it to adopt any conclusions; I simply request him to suspend his judgment,—to do as the judge advises the jury on a trial to do, namely, to dismiss from his mind all he may have previously heard, or any preconceptions he may have formed about the matter in question, and attend only to the evidence laid before him.

The reader will recollect that in the second and third chapters the Aqueous rocks were described as consisting principally of sand, clay, and lime, and their varieties, frequently and variously interstratified with each other. Now

there is no certain order or sequence preserved among these several kinds of rock or their varieties. The aqueous or stratified rocks form one great continuous or connected series of bed over bed and stratum over stratum, but no part of this series is characterized exclusively by the occurrence of any one kind of rock. Sandstones, conglomerates, clays, shales, slates, and limestones occur indiscriminately throughout the series, sometimes in one part of it, sometimes in another. Moreover we have seen in the third chapter that the very same group of beds which in one locality consists principally of one sort of rock, may in some other locality be composed of rock of an entirely different sort. It is obvious therefore that we cannot form any general or universal classification of the stratified rocks by their mineral or lithological character. If we attempted to do so, the grouping and arrangement of the subdivisions derived from one district would be stultified when applied to another. If however we follow out to their logical conclusions the descriptions given of the formation of aqueous rocks, it will be evidently possible to classify them according to their relative age.

If the aqueous rocks have been formed by the gradual and successive deposition of materials, bed over bed and

stratum over stratum, it is obvious that the lowest bed or stratum will be the oldest, and the uppermost the newest or most recently deposited.

At the very earliest period of the world's history in which water existed on the globe, and solid rock appeared above it, *whenever that period may have been*, the water must have exerted an erosive action on the rock, and the result of that wear and tear—the detritus, as we call it—must have been deposited *somewhere under the water*. That deposition of detritus formed the first aqueous or stratified rock ; and ever since that period a similar action has been going on somewhere or other on the earth's surface, and consequently a perpetual accumulation and deposition of detritus, now in one place, now in another, through age after age and century after century, down to our own days.

It is clear therefore that if we could discover any evidence or any characters by which we should know which were the first-formed aqueous rocks, which the next, and the next, and so on to the last, we should have a simple and obvious method of classifying them. We should also have in them a sort of record of the earth's history for the time during which they were deposited. We should at least find in them a measure of past time ; for just as we can now

measure time by the trickling of grains of sand from one bulb of the hour-glass into the other, so can we estimate, although but roughly, the amount of time past by the amount of sand and similar material transferred from one place to another by the action of natural forces. If we had an hour-glass open at both ends, and a perpetual stream of sand running through it, we should be able, by watching how much ran through in an hour, and measuring the whole quantity accumulated, to know how many hours it had been running. In the same way, if we can form any estimate of the amount of the accumulation of earthy matter (forming rock) in any given portion of time, and under certain given conditions, we arrive at a sort of standard by which to assign a limit to the time required for the accumulation of the whole series of earthy matters forming the aqueous rocks. In the case of our supposed open hour-glass, we could see at once from the size of the neck and the fineness of the sand, that it would not be possible to force through more than a certain quantity in a given space of time, though as the sand might have occasionally got clogged in the neck, or its running have been somehow interrupted for a time, we perhaps should not be sure that the actual time elapsed *was not greater* than that we assigned

to it. Just so in the case of the deposition of the aqueous rocks: having arrived at an estimate of the greatest possible quantity that could be deposited in a certain time, we could say what was the least possible quantity of time required for the formation of the whole series existing, although as there might have been great stoppages and interruptions in the accumulation of materials, and as it is possible that large portions, after being deposited, may have been subsequently destroyed, we could never be sure that the actual time elapsed during the formation of the series was *not much greater than* that at which we estimated it.

Now, have we any means of ascertaining which were the first-formed rocks, which the next, and which the last?

One means we have of ascertaining this is evidently "superposition," as it is called. From the very nature of the formation of Aqueous or Stratified rock, it is obvious that if we have one bed of such rock resting on another, the upper one must be the newer of the two, because as they were both formed by the successive deposition of materials at the bottom of some water, the lowest bed must have existed before the upper one could be deposited upon it. If therefore we could in any part of the globe find the whole series of Aqueous rocks regularly deposited one upon

the other, the mere order of their superposition would be at once the indication of the *relative age* of each of them. Now there are parts of the globe in which this supposed case actually occurs with respect to very large portions of the series of Aqueous rocks, although there is no part where it occurs with respect to the whole of them. One of those parts of the globe is England and Wales, and we do not as yet know any other part of the globe in which anything like so large a part of the series has been accumulated with such order and regularity, nor is exhibited so admirably to the research of the student. Had it not been for the fact of large portions of the series being thus preserved continuous and entire, it is very doubtful whether we should even yet have arrived at any tolerable notion of Geological Time. The reader then must bear in mind that "superposition of beds" lies at the root, and is the very foundation, of all our ideas respecting past geological time, and the history of the formation of the external portions of the globe.

Suppose however that we have two masses of Aqueous rocks, two groups of beds which do not touch each other, that either, existing in the same continuous land, they end before they come together, or that they are only found in different parts of the globe separated by seas of greater or less extent, how are we then to determine their relative ages?

It was at one time thought that this could be done by mineral character, or, more properly speaking, by lithological* character. It was supposed that the oldest rocks were always the hardest, most indurated, and most altered. This is now known to be a mistake, and no geologist trusts to the lithological character of a rock, except within comparatively limited spaces, and under certain precautions. We have however a more certain guide, because it has been discovered that the fossils found so abundantly in the Aqueous rocks give indications of their age, which are of far higher value and of much greater precision than lithological characters, and which, within certain limits and under certain restrictions, have been to geologists as yet an unerring guide.

It was observed by Dr. William Smith, in the early part of this century, when examining some of the southern and central districts of England, that the rocks, which there have a very well-defined lithological character, occurring in a very regular order of superposition, contained certain fossils, the kinds of which were peculiar to each rock. He saw that each great group of beds had certain fossils peculiar to itself, so that if one of these fossils were shown to him,

* From the Greek word *lithos*, a stone. Lithology, the science treating on the nature of stones or rocks.

he could with certainty state which group of beds it came from. This discovery has been extended and improved, until we can now put forward the following propositions as among the established facts of geology.

1. The entire series of aqueous or stratified rocks can be divided into certain portions, each of which is characterized by an assemblage of fossils peculiar to itself. This proposition is strictly geological.

2. Each assemblage of fossils has a greater resemblance to the assemblage just above and below it in the series, than it has to any assemblage more distant from it; the whole series of assemblages of fossils having a certain progressive character of such a nature that that characterizing the lowest or oldest rocks is most dissimilar from the organic beings existing in our own time, while those characterizing successively newer rocks gradually approximate to living beings, those of the newest rocks being scarcely to be distinguished from the animals and plants now inhabiting the globe. This proposition gives rise to a new science, called Palæontology.

We thus get from the fossils or organic remains contained in the aqueous rocks, two co-ordinate methods of establishing the relative age of the rocks.

1. If we look upon the fossils as mere marks, enabling us to identify two portions of the same group of rocks widely separated on the earth's surface, we are by their aid enabled to piece together two separate portions of the series. We can do this when we ascertain, by the identity of their assemblage of fossils, that any beds of these two portions are contemporaneous. We are thus enabled to extend our evidence of superposition.

2. We find the fossils themselves to bear about them the marks of their own relative antiquity, to carry their own geological date inscribed on the details of their structure, and thus are able to at once fix the date of the rock in which they are found, without reference to the fact of superposition at all.

If any one commenced the study of geology for the first time by the perusal of this little work, he might well have thought that he was entering on a dry and dusty road, leading through sterile and rocky tracts, into a region which might be grand or interesting, but which could hardly be beautiful or attractive. To such a reader I could fancy the last two pages, if the facts stated were new to him, would be like the sudden glimpse from among piles of barren rocks, into a rich and fertile valley glowing with all the

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[SLAND OF ST. PETER AND PAUL ISLAND]

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beauties of vegetation, and cheered by all the sound and motion of animated life.

Geology is not a mere dull and barren disquisition on the nature and composition of rocks and stones, but has become, incidentally as it were, and unawares to the geologist, the opening to a full, rich, and varied history of the earth, embodying the labours of the naturalist, the chemist, and the physicist,—of all who study the living beings that people it, the constitution of the matter that composes it, or the laws of force that act upon it,—into one great harmonious whole.

In the second proposition of p. 183 we catch a glimpse, if only a dim and indistinct one, into a grand and yet almost untrodden region of science, that which may be called the philosophy of organic existence. We see the remains, fragmentary and imperfect though they may be, of a series of assemblages of animals and plants peopling and clothing the world in times long antecedent to our own, intimately connected with, and in some mysterious and utterly unknown way leading up to, the assemblages of animals and plants now living around us.*

* The explanation of this subject has been attempted by what is known as the "Development hypothesis" of organic beings. This hypothesis origi-

This is a subject which is obviously beyond the bounds of our science. It is one belonging to the Natural Historian, including in that term the Anatomist, the Physiologist, the Zoologist, and Botanist, all who make the study of organic life the business of their lives.

To the Geologist proper, fossils or organic remains are merely so many empirically discovered marks, enabling him

nated with Oken, a profound physiologist, but one of whom it may almost certainly be said "much learning had made him mad." It was re-advanced in a clearer form by Lamarek, an admirable naturalist in his particular department, but more acute than profound, one of those ingenious, subtile, and dexterous reasoners who are particularly liable to fall in love with a specious hypothesis (especially if of their own creation), and apt to support it by such a show of reasoning and such an *admirable selection* of facts, as to render it very difficult of direct refutation, though it fails to convince the man of great and profound knowledge, fails to assimilate to itself all the future discoveries of the science, and remains for ever a barren speculation, often perhaps admired for its cleverness, but only received as true or probable by men of an intellect similar to that of its inventor. In our day the "Development hypothesis" has been again brought to light, with some slight modifications, by the author of the 'Vestiges of the Creation,' a man whose mind seems greatly to resemble Lamarek's, but who is clearly not, like him, a great naturalist,—not, like Oken, a profound physiologist,—nor is he apparently a master of Palæontology. Not a single zoologist of any eminence, so far as I am aware, has accepted this hypothesis as even probable, while those of greatest authority have always treated it with contempt, as unworthy of scientific notice.

The whole existence of this hypothesis depends upon negative evidence,—

to recognize the place in the chronological series of the rock containing them. For his objects, or at all events for the major part of them, it matters not whether the beings were ever alive or not. If they were so many different sorts of minerals, provided he could be assured of their having a definite chronological order among themselves, they would be just as valuable to him as a geologist, as they are now as organic remains. Of course he is interested, in common with all other lovers and students of physical science, and indeed with the world in general, in the wonderful history of the extinct races of animals and plants that have inhabited the globe, and he is more especially interested because this history has come to light in consequence of his own researches. He is like an engineer, who, having unexpectedly dug down upon a buried city with all its antiquities, is delighted to hear from the antiquarian the history and meaning of the things he has discovered. Such a man

upon the absence of facts to refute it, not upon the presence of facts to support it. It is an appeal to our ignorance, not to our knowledge. Its shallowness is only equalled by its presumption. Its reasoning on the most obscure, difficult, and unexplored subject in the natural sciences is on this wise:—"I say it is so and so, can you prove it is not?" It is in fact one of those hypotheses that, however amusing for a time, lose all their interest with their novelty, and gradually die away and are forgotten.

would be very likely to study history and antiquity for himself, and become an expert archæologist; and this has happened too in geology, for many geologists have almost given up the study of their own science for that of the ancient remains they have discovered. This latter science is called Palæontology, or the science of ancient living beings.

It has come to be almost deemed a part of Geology, because some considerable amount of knowledge of its results is absolutely necessary to the geologist, just as we have seen already that some acquaintance was necessary with the results of chemistry and mineralogy.

Palæontology is however a science of itself, and no more a part of geology than is mineralogy or physiology. One result of this is that the Geologist, unless he be also a Palæontologist, is not entitled to have an independent or original opinion on palæontological questions; he must accept the dicta of palæontology *on authority* from its recognized masters and professors, just as he accepts the dicta of chemistry and mineralogy. In this little book therefore we shall not attempt to meddle with palæontology as a science, though we may have occasion now and then to speak of some of its results.

NOTE.—I have heard the term Palæontology objected to by the metaphysician on the ground that Ontology is already used as a term in metaphysics, signifying the Science of Existence in the abstract. I confess I should be inclined (if it were allowable) to plunder the metaphysician of that seldom-used term, and appropriate it to the use of the Physicist (I do not mean the M.D., but the student of physical science), and give it the technical meaning of the “Science of *Organic* Beings.” By this use of the term “Ontology,” we should avoid the vague term “Natural History,” or the cumbersome periphrasis of “Zoology and Botany, and the Physiology of Animals and Plants.” We might then have the following compact and symmetrical nomenclature. *Ontology*, the Science of Organic Beings; divided into *Zoology*, the Science of Animals; *Botany*, or *Phytology*, the Science of Vegetables; or again specifically subdivided into *Cainontology*, the Science of now living organic beings; *Palæontology*, the science of extinct organic beings. Or *Ontology* and *Ontologist* might be used alone (unless when necessary), to signify the science, and the student, of the races of organic beings now living on the earth, while for those of the extinct races might be used the distinctive term *Palæontology*, divided into *Palæozoology* and *Palæophytology*.

Part II.

ON THE SERIES OF STRATIFIED ROCKS.

CHAPTER X.

ON THE NOMENCLATURE USED IN THE CLASSIFICATION OF THE AQUEOUS OR STRATIFIED ROCKS.

WE have seen in the last chapter that all Aqueous or Stratified Rocks are classified according to the relative date of their formation, this date being ascertained primarily by the fact of their superposition, or the order in which they rest one upon the other, but where evidence of that fails or cannot be applied, by the fossils or organic remains contained in them.

The reader must here be warned that this classification, or rather the nomenclature used in it, is at present in a very confused and unsatisfactory state. In order to understand it,

it is necessary briefly to state how it arose. We shall then see why certain terms were originally adopted, why and how they have been modified, and why others have been introduced.

Our present nomenclature was commenced by Lehman and modified by Werner. Their notions were that all the granites and other crystalline igneous rocks, and also the crystalline metamorphic rocks, such as gneiss, etc., were "Primitive rocks;" they supposed them to have been formed by the crystallization of mineral substances that had formerly been held in solution in a fluid menstruum. All the mechanically formed rocks, which were obviously composed of the detritus of such crystalline ones, they called "*Secondary rocks.*"

A third class, formed of the non-crystalline metamorphic rocks, was afterwards introduced between these two, and called "*Transition rocks.*"

When it was discovered by Hutton and others that many of the supposed Primitive rocks were in reality igneous, and had been formed after some of the so-called Transition and Secondary rocks, the nomenclature was modified. The term Primitive was discarded, and Primary substituted for it, which was made rather vaguely to include certain igneous

rocks, as granite, and the earlier aqueous rocks. The term Transition was retained for some time, having a technical sense attached to it, but was gradually disused, and is now laid aside. The term Secondary is retained up to the present time, having somewhat of a technical meaning. In addition to which, another class of rocks, newer than the Secondary, has been formed, and denominated "Tertiary:" that denomination is still retained.

When Sir C. Lyell showed that some of the so-called Primary and Transition rocks were really metamorphic, and that their peculiar mineral state and character was no sure indication of their relative age, a further modification became necessary; all rocks were separated into two great classes, Aqueous and Igneous, it being understood that *none* of the igneous were peculiar to any geological period, and that *any* of the aqueous might be made to assume more or less of the character of igneous rocks by metamorphic action.

The terms Primary, Secondary, and Tertiary, were and are still retained, but are confined entirely to aqueous or stratified rocks, the whole series of which is divided among those three great classes. As however these three classes of rock do not in any way differ from each other

as to their origin or their method of formation, it is not possible to distinguish between them by any mineral or lithological character. There is no essential difference between a Primary sandstone and a Tertiary one, or between any other rocks as they occur in the three divisions,—not even between a Primary, Secondary, or Tertiary limestone. Geologists therefore were compelled either to draw purely arbitrary lines, agreed on by mutual consent, to settle the boundaries of these divisions, or to have recourse to characteristics derived from the organic remains contained in the rocks. In fact, the boundaries were settled on both these principles: geologists and palæontologists have more or less universally agreed to consider organic remains of a certain kind to be characteristic and representative of the Primary rocks, another set of the Secondary, and another of the Tertiary. Palæontologists accordingly have adopted the following terms:—"Palæozoic," or characterized by ancient animals, for the earliest class; "Mesozoic," or characterized by middle animals, for the middle class; and "Kainozoic," or characterized by recent animals, for the newest class. We get then the three following classes, into which the whole series of stratified rocks is subdivided, commencing with the most ancient.

<i>Geological Terms.</i>	<i>Palæontological Terms.</i>
PRIMARY	PALÆOZOIC.
SECONDARY	MESOZOIC.
TERTIARY	KAINOZOIC.

Now each of these three great classes is itself subdivided into parts, which are called systems, formations, groups, series, stages, sets, etc. These terms have been used very vaguely, and it would savour perhaps of presumption if we were here to attempt to give them any definite meaning. They have all been used rather as synonyms than in any accurate order of subordination to each other*. It might

* After writing the above, I found that D'Archiac, in his 'Histoire du Progrès de la Géologie,' has treated of this subject in nearly the same way, and proposes the following nomenclature:—1. Terrain; 2. Formation, Système; 3. Groupe; 4. Etage. When speaking of portions of Geological Time, he proposes Epoch = Terrain, Period = Formation. If our English word "Ground," corresponding to "Terrain," were taken more into use, it might be advantageous, but it could hardly be adopted with so large a sense as is here given to Terrain. System, in English, seems to me to have on the contrary a wider and larger meaning than would allow it to take the subordinate place assigned to it by the French geologists. *Etage* is an admirable term, but unfortunately our translations "floor," "story," have such fixed technical meanings in other directions, that it seems difficult to use either of them. Stage is perhaps open to the same objection, but I have determined to adopt it, after in vain endeavouring to think of any better word. Miners often speak of "coal-measure ground," etc., and ground is a term which may come more into use hereafter.

perhaps be as well if the term "Stage" or "Set" were used as the lowest term, to signify an assemblage of beds, all having the same characters, both lithological and palæontological; the term "Group" to signify two or more Sets or Stages intimately connected; the term "Formation" to include two or more Groups; and the term "System" to signify several Groups or several Formations as the case may be, having certain general characteristics, enabling us to separate them as a symmetrical well-defined body from their immediate neighbours. Adopting this nomenclature provisionally, we can say that the subdivisions of the three great Classes are the following:—

PRIMARY CLASS.

1. The Cambrian Rocks	}	LOWER PALÆOZOIC.
2. The Silurian System		
3. The Devonian Formation	}	UPPER PALÆOZOIC.
(One or two Systems?)
4. The Carboniferous Formation		
5. The Permian Formation		

SECONDARY CLASS.

6. The Triassic Formation	}	LOWER SECONDARY.
(One or two Systems?)
7. The Oolitic Formation		
8. The Wealden and Neocomian Formations	}	UPPER SECONDARY.
(One System?)
9. The Cretaceous Formation		

TERTIARY CLASS.

10. The Eocene System	LOWER TERTIARY.
11. The Miocene Formation	} UPPER TERTIARY.
12. The Pleiocene Formation	
13. The Post-Pleiocene* Formation.	

Another defect and irregularity or want of symmetry in our nomenclature will be apparent to the reader, in the designations of the different Groups, Formations, and Systems. These designations are sometimes derived from a geographical position, as Cambrian, Silurian, etc.; sometimes from a mineral character, as Carboniferous, Oolitic, Cretaceous; sometimes from a provincial expression, as Liassic; sometimes from a certain proportionate character in the organic remains, as in all the Tertiary class.

The reader however need not be alarmed at this apparent confusion; the reason of the name is a very good thing to remember it by, but after a short time that reason is forgotten and disregarded; and the name itself is ordinarily used by us, just as we use the names of everything around us in our common conversation, without troubling ourselves to inquire or to remember their derivation.

One principle should here be stated as to the classifica-

* This division is by some called Quaternary.

tion of the Aqueous rocks, namely that in proportion as we generalize or extend our classification over the whole globe, we act more and more on purely palæontological grounds.

The mere thickness, or quantity, or complexity, of our different subdivisions of these rocks, must be looked on as local accidents; the disturbances that have affected them have the same local and partial character. During any of the geological periods it may have happened that in one district deposition of materials went on during the whole period, in another district during part of it only, while in another no deposition may have taken place at all. In the same way disturbances would happen at one locality, while others were left tranquil.

The races of animals and plants, on the contrary, must have been at least as common to the whole earth in former times as they are now; and we must suppose that equal changes in the assemblages of species of organic beings have always required an equal time for their production.

One result of this is, that in classifying the rocks of any large country, or in constructing a general classification for the whole earth, we must tabulate our subdivisions with reference to the changes that take place in the characters of the fossils, rather than to the magnitude and complexity

of the rocks or of the disturbances that have affected them. It may often happen that beds only a few feet in thickness may be of equal value (that is, may mark the lapse of an equal period of time) with another set of beds many thousand feet thick ; and indeed these few feet of rock may in other districts be found to swell out to massive and extensive formations.

In this way Palæontology, although discovered in consequence of the superposition of beds, and thus resting on that fact as its foundation, yet in many instances becomes a guide of far superior power and importance to its parent. It requires however, especially in its present imperfect state, to be used warily and with much caution, and only to be implicitly trusted when it speaks through a master mouth.

Having thus briefly described the origin of the classification and the grounds of the nomenclature of the aqueous rocks, we will proceed to describe the series in regular order, commencing with the lowest or oldest, or beginning at the bottom of the series and proceeding upwards.

It unfortunately happens however that this method of commencing the description of the series of stratified rocks, though perhaps it will be most convenient on the whole, forces us

to begin with a difficulty, and to attempt to describe first of all those rocks which are least easy to understand, and about which the fewest accurate results have been arrived at.

The reader will perceive part of this difficulty when he recollects the origin and considers the nature of metamorphic action. It is principally the action of heat proceeding from the interior of the globe, by which rocks that have been formed as aqueous rocks, and made up of the detritus of pre-existing igneous rocks, have been again more or less nearly assimilated to their original form, and in some cases perhaps entirely re-absorbed into the mass of the igneous rock. Now, though rocks of any age whatever are all equally capable of being thus acted on, it is clear that the older a rock is, the more chances it has had of being metamorphosed, simply by the fact of its having been longer exposed to the possibility of igneous rocks coming in contact with it. Moreover the older a rock is, the more does it become covered in some place or other with newer deposits, in other words, the deeper it gets into the earth; and therefore the nearer does it come to the source and origin of the heat that is the cause of igneous and metamorphic action.

We ought therefore, *à priori*, to expect that the lowest and oldest part of the series of stratified rocks has been the most changed and the most destroyed by the ravages of the internal fires of the globe. So much is this the case, that it is impossible for us to fix upon any line of demarcation or upon any groups of rock, and say here commences the stratified series.

It is impossible for us to begin with the beginning, because we cannot find one; and we are compelled to commence with an arbitrary division, and assign a common date to certain rocks found in many parts of the globe which for all we know may be of vastly different ages.

As a matter of fact, in all countries, wherever the apparent base of the stratified rocks is exposed, that base is found to consist of metamorphic rocks, such as Gneiss and Mica Schist. Both the date of deposition and the date of the metamorphism of these rocks may be various. In any case where we find rocks wholly metamorphosed, all we can say of their age is that they are older than the rocks that rest upon them, unless we can trace them into some district where the metamorphism gradually ceases, and their exact geological date can be discovered by their organic remains.

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If now we dismiss from our consideration these highly altered rocks, and if we take, as the safest and best-known ground, the British Islands for our examination, we can say that the lowest or oldest stratified rocks we have, are those called Cambrian or Cumbrian.

1. THE CAMBRIAN OR CUMBRIAN ROCKS.

The word “rocks” is used here, instead of “system” or “formation,” because we cannot yet precisely tell the value of the Cambrian Division. Cambrian means the rocks of Wales, Cumbrian those of Cumberland and Westmoreland. In Wales these rocks consist of certain thick sandstones, gritstones, and conglomerates, with interstratified beds of green or green and purple slates. It is in the uppermost of the slate-bands of this Cambrian group that the great Penrhyn and Llanberris slate-quarries are opened. They contain no fossils. These rocks are found to have a thickness of upwards of 20,000 feet in some places in North Wales, but as the base of them is never exposed, we know not how much greater thickness they may possess, nor what is below them. One portion of this division has been provisionally called the “Barmouth and Harlech sandstone group.” Their upper

boundary is a purely arbitrary line, along the top of a certain set of beds, drawn by the officers of the Geological Survey of Great Britain, under the direction of Sir H. T. De la Beche, C.B.; their reason for drawing it being simply that no fossils have as yet been found below that line, whereas fossils are pretty abundant in many places above it.

It must not be forgotten that Professor Sedgwick (of whose peculiar department we are now speaking, he being the one geologist who has single-handed done far the most to unravel the structure of these older rocks) dissents from this placing of the boundary of the Cambrian rocks, and himself places it much higher, so as to include the beds we shall subsequently speak of as Lower Silurian; dividing his system into Upper and Lower Cambrian. There can be no doubt that if we neglect the fossils, and look only to the physical structure and position of the rocks of Wales, Professor Sedgwick is right. There can be no reason for drawing the boundary where it has been drawn, and along no other geological horizon in North Wales, except the fact that fossils have been found in all the rocks above that line of division, and in none of those below. Whether they may not hereafter be found is another question.

If we go to Cumberland, Professor Sedgwick there describes the Cambrian, or as he then calls them the Cumbrian rocks, as likewise consisting of Upper and Lower, and gives the following abstract of them :—

		FEET.
CAMBRIAN	{ Upper	{ Coniston Flagstone 1500
		{ Coniston Limestone 300
		{ Slates and Porphyry 10,000
	{ Lower	Skiddaw Slates 6000

He describes these however as all fossiliferous, which by the rule lately mentioned would exclude them from being considered as Cambrian at all, more especially as the fossils of the upper beds are such as Palæontologists seem agreed to consider of Silurian age. It is highly probable that the Skiddaw slates are of the same age as the “Barmouth and Harlech Sandstone Group” of North Wales, which likewise contains the best roofing slates of that country. In that case, according to the classification adopted by the Geological Survey, the Skiddaw slates would be considered Cambrian, and all above them as Silurian.

The reader will see from these statements that this part of the classification of the Stratified rocks is far from being settled. There is however no dispute about the things

themselves; the rocks are all known, and their order completely ascertained; the uncertainty is merely as to the name by which certain portions of them shall be called.

It has been proposed to cut off the Cambrian rocks, considered as marked by the absence of all organic remains, from the rest of the Palæozoic rocks, and to form a separate class, called Azoic (or destitute of animals), for all the rocks below those of the Silurian system. This appears to me to be premature, to say the least of it. It rests on the assumption, not only that no fossils have been found in rocks below the Silurian, but that no animals existed before the lowest Silurian rocks were deposited. It would suppose *Lingulæ* and *Trilobites* to be the first of all created beings,—a hypothesis that, to say the least of it, seems a very singular one, and for which it is difficult even to imagine any reason, fitness, or congruity with what we know of the laws and order of Nature*. “De non apparentibus et de non

* To avoid all possibility of mistake on the part of persons who, while well-intentioned, are sometimes rather short-sighted, and not always particularly charitable, I beg to state here that I use the term “Nature” as a reverential periphrasis to avoid introducing into a scientific discussion a name of a more awful character, and the consequent *quasi*-infraction of the Third Commandment.

existentibus eadem est ratio," is doubtless a sound legal maxim, but in science it only holds good as forbidding any reasoning at all about the things in question: to argue that things do not exist, because we cannot find any traces or remains of them, is to estimate by the deficiencies of our own powers and faculties the omnipotence and superabundance of Nature. So little credit do I personally attach (if I may be allowed to speak of myself) to negative evidence in the matter of organic remains, that, to take up extreme ground at once, I hold myself perfectly prepared, if I live long enough, to hear of the discovery of the Silurian Mammalia, and of course of all those of the more recent periods. I am therefore individually quite prepared to hear sometime of the discovery of fossils older than Silurian forms, but certainly not at all inclined to amuse myself and others by endeavouring to prophesy what they will be like.

CHAPTER XI.

PRIMARY OR PALÆOZOIC ROCKS (CONTINUED).

2. THE SILURIAN SYSTEM.

THIS system of rocks is subdivided into two, Upper and Lower. The original classification of Sir R. Murchison, the first systematic describer and surveyor of this system, was as follows, put into the provisional nomenclature adopted in this book :—

For- mations.	Groups.	Stages or Sets of Beds.	Thickness in feet.
UPPER SILURIAN.	{	{ Upper Ludlow Rock. Aymestry and Sedgley Lime- stone.	{ 1500 2500
		{ Lower Ludlow Rock.	
	{	{ Wenlock and Dudley Lime- stone.	{ 1000
		{ Wenlock Shale	
LOWER SILURIAN.	{	{ Caradoc Limestone.	{ 2000 ? 3200
		{ Caradoc Sandstone.	
	{	{ Llandeilo Flagstone and Lime- stone.	{ 1200 ?

In these detailed classifications and measurements we must always be understood as having in our eye a certain district in which the rocks are found as they are thus described, and which is referred to as exhibiting a type of the group or formation in its most perfect character. In proportion as we recede from that district in any direction, the subdivisions, whether of groups or stages, are apt to get indistinct. For instance, if we trace the Upper Silurian rocks either into North Wales on the one hand or into South Wales on the other, we can no longer distinguish either between the several parts of the Ludlow and Wenlock groups, nor finally between the groups themselves. The Upper Silurian rocks of Denbighshire, for instance, are a series of flagstones, slates, and sandstones, in which it is impossible to draw any boundaries so as to construct any groups either by lithological or palæontological characters. Similarly in the Lower Silurian of the above tabular form, we should find that, when we trace the Caradoc sandstone far from its typical country of Siluria*, it both alters its character and its thickness, and often thins out and ends

* By Siluria is meant the country of the ancient British tribe, the Silures, inhabiting the borders of England and Wales, one of whose kings was Caradoc, or Caractæus.

altogether. As to the Llandeilo flags, the group ought really have been described as a mere provisional one. In a certain part of South Wales, a series of flagstones and slaty rocks, with some limestones, was found under what was supposed to be the Caradoc sandstone, and the thickness of it was arbitrarily assumed at about 1200 feet. No positive base however was assigned to it, and it was afterwards found, when the Government Survey went over the ground with more accurate and detailed work than was in the power of any single individual, that this 1200 feet was but the top of a great group of rocks of vast thickness and dimensions.

No detailed account of this great group has yet been published by the Survey, but the following is an abstract of a paper read by Mr. Selwyn and myself to the Geological Society in 1848. This paper was descriptive of a part of the country, not near Llandeilo, but in North Wales. Above the Barmouth and Harlech sandstones mentioned before as belonging to the Cambrian rocks, came a great series of blue and grey slates and flagstones, with beds of a grey calcareo-feldspathic ash, over which many were some very thick black slates, likewise interstratified with ash and with contemporaneous feldspar-trap and por-

phyry. The total thickness of this, called the Trappean group, was 15,000 feet.

Above it was a series of beds called the Bala group, consisting of black slates below; grey, fine-grained, gritty slates and gritstones in the middle (containing a thin band of impure limestone called Bala limestone, under which was a bed of ash); and black slates again at top, capped by a band of very pale slate. This series was 9000 feet thick. Above this came the Caradoc sandstone, consisting there of yellow or whitish sandstone, interstratified with black slate, and more than 2000 feet thick*.

As a result of these and other observations, the classification of the Silurian System has to be somewhat modified. The Caradoc rocks had better perhaps be taken from the Lower, and placed as an intermediate group between Lower and Upper Silurian, but considered as a variable and inconstant member, which may or which may not be present. It is probable that not only does the Caradoc sandstone (like most other sandstone formations) thin out rapidly, but that the Wenlock shale sometimes overlaps it, or is unconformable to it. It is probable also that the Caradoc

* These statements are provisional, waiting the publication of Professor Ramsay's Memoir on North Wales.

sandstone sometimes overlaps or is unconformable to the Lower Silurian. It is absolutely certain that the Upper Silurian rocks, when the Caradoc sandstone is absent, are often violently and widely unconformable to the Lower Silurian rocks, though they too may also, and do, repose in some districts conformably for many miles.

The reader will recollect that I described the Cambrian rocks of North Wales as separated from the base of the Silurian rocks of that country by a purely arbitrary line. There is no appearance of unconformability between the two, and physically they blend together, and are as intimately united as are any of the groups of the Lower Silurian rocks themselves. Depending on physical evidence alone, there is no break in the succession of rocks of North Wales, from the lowest bed visible, up to the base of the Caradoc sandstone; there is then an occasional unconformability and a change of lithological character, which, looking to that physical evidence alone, would lead a geologist to draw a strong boundary there, and to consider all below as one connected series, and all above as separated from it.

Palæontologists however seem to be agreed that the fossils of the Upper Silurian, both in and above the Caradoc sandstone, are so similar and so intimately united with those

of the Lower Silurian, that they must be looked on as one palæontological system. This system however seems to be an extended one, and to be of equal value not with any of the other *portions* of the palæozoic rocks, but with the whole of them; so that there is as much geological difference (taking all characters, physical and zoological) between the subdivisions of the Silurian System, as there is between the Devonian, Carboniferous, and Permian rocks, hereafter to be described. This would give to the term “Silurian” a technical and accidental importance equal to the expression “Lower Palæozoic Rocks,”—an importance which, though acquired by accident, it seems likely to retain as long as our present provisional nomenclature shall happen to be preserved*. It has now the authority of

“*Usus,*

Quem penes arbitrium est et norma loquendi,”

and will probably keep that authority till some other “*usus*” comes in and supersedes it.

* Should a geologist cast his eye over these pages, he will see that there is alluded to, here, a matter which has lately caused some little controversy in England between Professor Sedgwick and Sir R. Murchison. If I give my opinion in a note, I hope it will not be attributed to presumption on my part, but simply because I think no good comes from not speaking out on such points. I may claim impartiality, because Professor Sedgwick, on the one side, is my old master, my geological father and friend; on the other hand,

Taking now North Wales and its borders as exhibiting the best and fullest type of the Silurian rocks of Britain, we can give the following synoptical view of them in ascending order.

LOWER SILURIAN. (UPPER CAMBRIAN, *Sedgwick*.)

1. The Trappean Group.—A succession of black slates, with occasional bands of sandstone and gritstone, and great masses of contemporaneous feldspathic trap and beds of trappean ash. Maximum thickness, 15,000 feet.

2. The Bala Group.—Black and grey slates with grey and brown gritstones and sandstones, one or two beds of ash, and one or two thin bands of limestone. Maximum thickness, 9000 feet.

Sir R. Murchison's view is the one taken by the service to which I belong—the Geological Survey of the United Kingdom. It appears to me then that had it so happened that the structure of North Wales had been equally simple with that of Siluria, and Professor Sedgwick had published an account with maps, sections and figures, and description of fossils, contemporaneously with the appearance of the "Silurian System," and under the title of "Cambrian System," that what are now called the "Lower Silurian Rocks" would have been called the "Cambrian Rocks," and the two terms Cambrian and Silurian would have been bracketed together to form the "Lower Palæozoic Rocks." In consequence of the want of such a detailed exposition of the "Cambrian series," the term "Lower Silurian" has been generally adopted, and will now be used as a technical term, without regard to the strict logic of its derivation or the exact justice and propriety of its use.

INTERMEDIATE.

3. Caradoc Formation. — In some places beds of strong brown and grey sandstones, passing up into highly calcareous sandstones, and shelly limestone. In other places thick brown sandstones with occasional beds of conglomerate, alternating with beds of black shale, often cleaved into slate. Maximum thickness, 5000 feet.

UPPER SILURIAN.

4. Woolhope and Barr Limestone. — Argillaceous, concretionary limestone, often nodular and interstratified with beds of shale. Maximum thickness, 50 feet.

5. Wenlock Shale. — Bluish or greenish grey compact shale, sometimes arenaceous, sometimes calcareous. Maximum thickness, 700 feet.

6. Wenlock Limestone. — Irregular beds and large concretionary masses of impure argillaceous limestone, highly crystalline pure limestone, flaggy limestone, and shale with calcareous concretions. Maximum thickness, 300 feet.

7. Lower Ludlow Rock. — Chiefly “mudstone” or very argillaceous sandstone, often flaggy or shaly, not often calcareous. Maximum thickness, 1000 feet.

8. Aymestrey Limestone. — Hard, nodular, concretionary argillaceous limestone. Maximum thickness, 100 feet.

9. Upper Ludlow Rock.—Principally greenish argillaceous sandstone or “mudstone,” often with highly calcareous sandstone, capped by some thin red argillaceous flagstone, called “Tilestone.” Maximum thickness, 1260 feet, including the “tilestone.”

The total maximum thickness then of the whole Silurian System, as developed in the North Welsh district, is upwards of 32,000 feet*.

If we leave Wales and its borders, we shall find in the Lake district of Cumberland the Upper Silurian rocks to consist, according to Professor Sedgwick, of

1. Kirkby flags and coarse slates.	} Answering
to	1. The Ludlow group.
2. Ireleth slates.		2. The Wenlock group.
3. Coniston grits.		3. The Caradoc group.

while the Coniston flagstone and limestone answer to the Upper Bala rocks and Bala limestone, and certain slates

* The reader must not suppose that it necessarily follows that there is that thickness of these rocks *in any one spot*. The maximum thickness of each division is stated, because, among other reasons, it gives us a measure of past time. If one thousand feet of rock is deposited during one period of time, and another thousand during another period, it matters not for our reasoning whether the last thousand was placed directly on the first thousand, or deposited in some other place, so long as we can show that the deposition of the last thousand did not commence till after that of the first was completed.

and porphyries correspond to the Lower Bala rocks and the Trappean group, all which by Professor Sedgwick are called Upper Cambrian, by others Lower Silurian.

In the south of Scotland, the great band of high Border country, of which the Lammermuir Hills are part, is composed of Lower Silurian rocks, described by Professor Nicol as more than 30,000 feet thick, full of contemporaneous and intrusive igneous rocks, and resembling the Lower Silurians of North Wales already described. Mr. Harkness describes, in the Lower Silurian rocks of Dumfriesshire, a band of anthracite and carbonaceous shales.

In Ireland there may possibly be some Upper Silurian rocks on the western side of the island, as noted by Mr. Griffith in his map; but on the eastern side of the island Lower Silurian rocks alone are to be found, exactly resembling those of Wales and the south of Scotland.

In Russia the Silurian rocks, as described by Sir R. Murchison, are generally in a nearly horizontal position, and quite unaltered from their original condition, over large districts, as around St. Petersburg, being as soft and as unconsolidated as the most recent rocks of other parts of the world. Near St. Petersburg they consist, in the ascending order, of

LOWER SILURIAN ROCKS.

1. A blue clay, used for bricks and pottery. Several hundred feet thick.

2. Ungulite grit, so named from a peculiar fossil it contains. A white or ferruginous sandstone, sometimes calcareous, not much exceeding 100 feet in thickness.

3. Bituminous schist, like that of the coal-measures or Kimmeridge clay of England, of inconsiderable thickness.

4. Pleta, or orthocerite limestone, a dull red and dingy grey, earthy and slightly consolidated limestone, with thin seams of clay. It had from its lithological characters been spoken of as chalk-marl. It is in some places capped by yellowish-white sandy calcareous flagstones. Thickness not stated, apparently not exceeding 200 or 300 feet as a maximum.

LOWER SILURIAN ROCKS,

Some of which are seen in some islands in the Baltic, others on the flanks of the Ural.

5. Sands, possibly representing Caradoc sandstone.

6. Limestone with corals, possibly representing the Wenlock limestone.

7. Calcareous flags, possibly representing the Ludlow rocks.

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On the flanks of the Ural mountains, many of the Lower if not of the Upper Silurian strata are metamorphosed into gneiss and mica-schist, or similar rocks.

The Silurian System of North America has now been very well surveyed and described by the American geologists. The following is a list of their subdivisions, in ascending order, as grouped by Sir C. Lyell from Mr. Hall's report.

LOWER SILURIAN.

1. Potsdam Sandstone : a thick quartzose sandstone, over which is a Calciferous or calcareous sandstone*. 250 or 300 feet thick.

2. Trenton Limestone and Black River Limestone group : thick limestones interstratified with shale. Total thickness, 560 feet.

3. Hudson River and Utica group, consisting of black shale below, with shales, shaly sandstones, and bands of limestone above. The lower black shales are the "Utica slates" of American geologists, which are 75 feet thick.

UPPER SILURIAN.

4. Niagara and Clinton groups, containing the Oneida

* Anthracite coal is found in this calciferous sandstone. The thicknesses here stated are from Dr. Emmons's Report.

conglomerate and grey sandstone, the Medina sandstone, the Clinton group of green shales and limestones, and the Niagara shale and limestone.

5. Onondaga salt group, consisting of red and green marls with gypsum and brine-springs, capped by magnesian and hydraulic limestones, the whole exceeding 1000 feet in thickness.

6. Helderberg group, containing the Pentamerus limestone, the Delthyris shaly limestone, the Encrinal limestone, the Upper Pentamerus limestone, the Oriskanny sandstone*; the Cauda-galli and Scholarie grits, and the Onondaga and Corniferous limestones.

7. Hamilton group, containing the Marcellus shale, the Moscow and Ludlowville shales, with an encrinal limestone, the whole varying from 300 to 700 feet in thickness, and the Tully limestone, which never exceeds 20 feet†.

The Silurian rocks of North America, like those of

* Mr. Sharpe, from the examination of the fossils brought home by Sir C. Lyell, is inclined to draw a very strong boundary-line here, and to look on the Oriskanny sandstone and the remaining rocks as Devonian. He makes the rocks immediately below = Wenlock, and says the Ludlow has no representative.

† These thicknesses are from Mr. Vanuxem's Report, who also mentions coal as occurring in the Marcellus shales.

Russia, are often horizontal, undisturbed and unaltered over very widely-spread districts.

Silurian rocks are known to exist in many other parts of the world, but they have not yet been thoroughly surveyed and described. Those of Bohemia have been surveyed by M. Barande, and form a very complete series; his descriptions however have not yet been published.

3. THE DEVONIAN FORMATION.

In some parts of the district of Siluria, the Upper Ludlow rocks are covered by some thin red shales and flagstones, locally called Tilestones. These, which are stated to be nearly 800 feet thick, were formerly considered as forming part of the Old Red Sandstone, but are now classed by Murchison as the top of the Silurian rocks. Over these tilestones we have in the border counties of England and Wales a thick mass of red sandstones and marls, often spotted with green and variously mottled. Interstratified with these are certain beds of impure concretionary limestone, locally called "cornstone," each bed rarely exceeding twenty feet in thickness and thinning out in all directions. Above that set of beds we have sandstones and marls of similar character, which in

the upper parts become conglomeritic, and in some places pass into thick beds of coarse quartzose conglomerate. The whole mass of the Old Red Sandstone thus variously composed, is in some places upwards of 10,000 feet in thickness.

It may be said to be a general rule in Geology, that sandstones and conglomerates are the most irregular of all beds in thickness and extent. Accordingly we find that even in North Wales the Old Red Sandstone is sometimes altogether absent, and sometimes is represented by a thin band of red sandstone and marl fifty or sixty feet thick, or by a mere local cake of those materials, never more than a hundred feet thick. All over the North of England it has these same characters. In Scotland however it again acquires a very large development, being at least 3000 or 4000 feet thick; consisting of

1. Roofing and paving stone, highly micaceous and slightly calcareous*.
2. Conglomerate, often of vast thickness.
3. Red and mottled marls, cornstone, and sandstone.
4. Yellow sandstone.

Another general remark we may here interpolate, is that, wherever we have a stage, group, or formation of rocks,

* Sir C. Lyell's account.

having principally or altogether a rudely mechanical composition (coarse sandstones and conglomerates), we may expect to find in some other locality, the corresponding or contemporaneous fine-grained tranquilly formed beds, and beds perhaps of chemical origin, namely, fine sandstones, clays, shales, and limestones. Accordingly it is now believed that the fine-grained compact limestones and slate rocks of Devon and Cornwall are really of the same age as the Old Red Sandstone of the rest of England and of Scotland. The way in which this result was arrived at, shows the advantage of Palæontology to Geology in a striking manner. The Old Red Sandstone is the intermediate series of rocks between the Silurian and the Carboniferous formations. It contains few or no fossils except certain fish. The slates and limestones of Devon abound in fossils, some of which resemble those of the Silurian rocks, some those of the Carboniferous, while some are peculiar to the rocks of Devon. The fossils of these Devonian rocks therefore prove them to occupy an intermediate place between the Silurian and Carboniferous formations, or the same place that the Old Red Sandstone occupies. The Old Red Sandstone therefore and the Devonian rocks are merely different parts of the same group or formation, to which, partly for euphony's sake,

partly as pointing to the most fossiliferous district, the name Devonian is applied.

Pure physical geology would have failed to make this discovery, on account of the interposition of the Bristol Channel between the two districts in one direction, and that of the flats about Bridgewater in Somersetshire in the other. Professor Sedgwick, to whose and Sir R. Murchison's labours we are indebted for much of our knowledge of the Devonian formation, gives the following tabular arrangement of the whole, combining the rocks of Scotland, the borders of England and Wales, and those of Devon and Cornwall into one view. It must be stated however that this arrangement is only a provisional one.

DEVONIAN FORMATION.

LOWER OR PLYMOUTH GROUP.	{ Dartmouth slate. Plymouth limestone and red grit, and Liskeard slate.
MIDDLE OR CAITHNESS GROUP.	{ Hereford sandstone, marl, and cornstone. Dipterous flag.
UPPER OR PETHERWIN GROUP.	{ Petherwin slate and Clymenia limestone. Marwood sandstone.

Mr. Sharpe has since proposed an arrangement founded on that of M. Dumont in Belgium, which would greatly modify the views above stated. This arrangement would

consider the Upper or Petherwin group of Professor Sedgwick as probably belonging to the carboniferous formation rather than the Devonian, and would place the Lower or Plymouth group as above the Old Red Sandstone of South Wales and Scotland.

It is not unlikely that it is to the South of Ireland we must look for the ultimate complete arrangement and harmonizing of the Devonian formation in the British Isles, because we there seem to have both the Old Red Sandstone type of Siluria and Scotland, and the slate and limestone type of Devon and Cornwall, and to have them in connection, so that we can directly observe their order of superposition.

On the east, as in Kilkenny and Waterford, we get the following in ascending order:—

1. Beds of breccia, containing fragments of slate, resting on the upturned edges of Lower Silurian slate rocks, over which are thick beds of quartzose conglomerate and red and dark-brown sandstones; above these are red and brown sandstones with occasional white sandstone and interstratified beds of red slate (cleaved marl), with bands of calcareous rock (imperfect cornstone) much decomposed. 3000 feet.

2. Beds of yellow and white sandstone, with occasional red sandstones, interstratified with red and green slate, passing upwards into yellow sandstones with greenish flagstones, and beds of green or red shale (often cleaved into slate). 500 feet.

Over these is the Carboniferous Limestone.

Tracing these beds south-westward into the south-west part of the county of Cork, we find this formation gradually assume the following type:—

1. Grey, green, and purple sandstones and gritstones, with bands of blue slate of great but unknown thickness, probably lower than any part of the eastern beds.

2. Red slates and sandstones, with occasional hard grey and greenish grits and sandstones, often slightly calcareous. Upwards of 3000 feet.

3. Hard grey grits and yellow sandstones, with interstratified bands of red and green slate. 800 feet.

4. Blue slates and grey grits with calcareous bands: occasionally varying from 500 to 5000 feet thick.

Of this series, No. 1 is supposed by Mr. Griffith to be possibly Upper Silurian; and No. 3 and 4 to be rather Carboniferous than Devonian rocks. It has hitherto appeared to me that they are all so intimately connected, and

their beds so interstratified, that it is impossible to separate them by any strong boundary-lines from each other. Palæontological evidence may possibly hereafter show that Mr. Griffith's ideas were to a certain extent well founded, and that we have in the upper group, No. 4, the true passage-beds from the Devonian into the Carboniferous formations. As this portion of Ireland however is now being surveyed by the Government Geological Survey, I cannot give more detailed or accurate results until the survey is complete.

The Devonian rocks of the Rhenish provinces and the adjacent parts of Germany resemble those of Devon and Cornwall in lithological character, rather than those of South Wales and Scotland. They have been arranged by M. Dumont in a very complete and symmetrical form, as follows :—

Terrain Anthraxifère.	{	1. Système houiller = Coal-measures.
		2. Système condrusien = Carboniferous Limestone.
		3. Système eifelien.
Terrain Rhénan . . .	{	4. Système ahrien.
		5. Système coblentzien.
		6. Système gedinnien.

Of these, Mr. Sharpe says No. 6 is true Upper Silurian = Tilestone of Murchison; we have therefore 3, 4, and 5, to represent the Devonian formation; or, if Mr. Sharpe's

ideas be correct, 3 = Devonian rocks, 4 and 5 = Old Red Sandstone.

The Devonian rocks of Russia consist of red sandstones and marls containing gypsum and rock-salt, whence they were always supposed to be the New Red Sandstone, till they were shown by Murchison and De Verneuil to be the same as the Old Red, from their containing the same fossil fish.

The Devonian rocks of America, according to the reports of the State geologists, consist of the following beds:—

1. Genesee Shale*.—Black shale, with flagstones and sandstones. Probably 1000 feet thick.

2. Portage or Nunda Group, consisting of the Cashaqua shale, the Gardeau shale and flagstones, and the Portage sandstones. Exceeding 1000 feet.

3. Chemung Group.—Highly fossiliferous shales and thin-bedded sandstone, black, olive-green, and grey. 1500 feet.

4. Old Red Sandstone.—The rocks to which they have given this designation in America consist of sandstone,

* To Sir C. Lyell is due the placing of the boundary between the Silurian and Devonian rocks of North America, at the base of the Genesee Shale. (See his *Travels in North America*, 1845.) Mr. Sharpe has subsequently, in a paper published in the 'Geological Journal,' placed it much lower. See p. 218.

shale, conglomerate, and impure limestone, generally red, but sometimes grey and green. They contain some of the same fossil fish as the Old Red Sandstone of Scotland. Varying greatly in thickness, sometimes perhaps two or three thousand feet, say 2500 feet.

In New South Wales and Tasmania (Van Diemen's Land), as also in the northern part of the colony of Swan River, rocks exist which from their fossils appear to be of Devonian age. They consist of limestones, shale, and sandstones. Coal is found at no great distance above the limestones ; but whether it is of Devonian age is not yet known, as it has not yet been ascertained whether the Devonian-like fossils have been found *above* the coal or not.

CHAPTER XII.

PRIMARY OR PALÆOZOIC ROCKS (CONTINUED). CARBONIFEROUS AND PERMIAN FORMATIONS.

4. CARBONIFEROUS FORMATION.

THIS great and important formation, like those previously described, exhibits a considerable variation in general structure in different localities. Its description may perhaps be best given by first of all taking two districts of Britain as exhibiting it in its most regular and typical form, and afterwards comparing other districts with that form. These two districts are (1.) South Wales, and (2.) Derbyshire and the adjacent counties.

In South Wales we get, resting on the Old Red Sandstone, a band of about a hundred feet in thickness, of black fossiliferous shale, called the Lower Limestone Shale, over

which are beds of thick limestone, called the Mountain or Carboniferous Limestone. The following is a synopsis of the whole formation, taken from the published sections of the Geological Survey of Britain (ascending order) :—

1. Lower Limestone Shale : about 100 feet.
2. Carboniferous Limestone : limestone, with occasional partings of black shale : from 500 to 1500 feet*.
3. Millstone Grit or Farewell rock, white quartzose sandstone and conglomerate : 300 to 600 feet.
4. Coal Measures : a great series of alternations of sandstones and shales, with occasional beds of coal, from 8000 to 12,000 feet in total maximum thickness.

In the Derbyshire district we get the following groups or series :—

1. Mountain Limestone, the base of which is not exposed, consisting principally of thick limestone†, occasionally interstratified with black shales, and exceeding 1200 feet.

* In other places, as near Bristol, the lower shale is 500 feet, the carboniferous limestone is 2338 feet, and the millstone grit 950 feet thick. (Sir H. De la Beche, *Memoirs of Geological Survey*, vol. ii.)

† The Mountain Limestone often contains rows of nodules and irregular plates and bands of black or white chert, just like the flints in the chalk. Many portions of the Mountain Limestone also are magnesian, or Dolomite as it is called.

2. Limestone Shale : black shales with thin interstratified limestones ; in some places 400 to 650 feet.

3. Millstone Grit : strong sandstones, with occasional small conglomerate interstratified with shales and a few small beds of coal ; about 1700 feet.

4. Coal Measures : alternations of sandstone and shale, with beds of coal and ironstone ; total thickness 2700 feet and more*.

Proceeding from the Derbyshire district towards the north, a gradual change takes place in the Carboniferous formation, in such a way that it becomes more and more a series of coal-measures from top to bottom. The Millstone Grit is never anything more than the lower part of the coal-measures, in which beds of strong sandstone occur. These, as we proceed north, become more and more split up and interstratified by beds of shale and occasional beds of coal. The Limestone Shale too, of Derbyshire, further north, becomes split up by beds of gritstone and limestone, and still further north by beds of coal. Lastly, the Mountain Limestone itself becomes split up and interstratified, first by beds of shale, then by beds of shale and sandstone, and

* This is on the Nottinghamshire side ; on the Cheshire side the thickness is much greater.

lastly, on the borders of Scotland, by shales, sandstones, and coals.

In the midland counties of England, namely in Leicestershire, Warwickshire, Staffordshire, and Shropshire, the Carboniferous formation consists simply of the upper group of the formation, the coal-measures. Little patches of Mountain Limestone are found below them in one or two spots in the first- and last-named counties, but usually the coal-measures rest directly and unconformably on Silurian and still older rocks. In Staffordshire several beds of coal come together by the thinning out of the intermediate measures, and make a mass of coal which in some places is upwards of thirty feet thick, in from ten to thirteen beds.

In Scotland the Carboniferous formation admits of no subdivisions into groups. Immediately above the Old Red Sandstone are coal-measures, containing beds of coal, over which are thick arenital limestones, interstratified with shales, so that no single mass of limestone is more than forty feet thick. The whole series of Carboniferous rocks in Scotland is said to be upwards of 6000 feet thick, the whole being coal-measures, with interstratified beds of limestone in the lower portion, representing the Mountain Lime-

stone of England. The whole series is said to be composed of materials in the following proportions:—

	FEET.
Sandstone	3300
Shale	2160
Limestone	306
Coal	180
Clay	132
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These materials are so disposed that there never is an unbroken set of beds of more than the following thickness of each sort:—

	FEET.
Sandstone	200
Shale	130
Limestone	40
Coal	13
Clay	28*

Small bands and nodules of clay ironstone are found occasionally in all the shales and clays of the carboniferous rocks of England, Scotland, and Ireland, but though of economical value, they are not of great geological importance.

In Ireland the carboniferous rocks consist, in the south and west, of two subdivisions—Carboniferous Limestone

* Mr. Milne, as quoted in Nicol's 'Guide to the Geology of Scotland.'

G. V. Du Noyon, del.

COFFINS IN GRATTIE, BALLYLOO, NEAR CARLOW, IRELAND.

Hallwardel & Walter, lith.

and Coal-measures. The Carboniferous Limestone, the maximum thickness of which is about 3000 feet, is locally again subdivided into three parts:—*A.* Lower Limestone; *B.* Calp, a series of dark limestones, interstratified with black shale; *C.* Upper Limestone. The Coal-measures consist of alternations of shale and sandstone, with a few thin beds of coal, principally anthracite or culm, and have a thickness of more than 2000 feet in the Queen's County.

In the north of Ireland the carboniferous rocks seem to assume more of the type of those of Yorkshire and the north of England. The coal-measures are still confined to the upper portion; but the lower part seems to consist of alternations of shale and sandstone with various thick beds of limestone, so that it may be doubted whether the subdivisions of the Carboniferous Limestone of the centre of Ireland can be accurately traced into the north or north-west.

The carboniferous formation of Belgium admits of a three-fold subdivision (ascending order):—

1. Arenaceous shales,—grey shales, limestones, and pisolitic iron ore, over which are grey sandstones and anthracite.
2. Limestone group,—erinoidal, dolomitie, and *Productus* limestones, with chert and anthracite.
3. Coal-measures,—shale and sandstone, with coal.

The formation is found also at St. Etienne in central France, where it appears to consist of conglomerate and sandstone below, and shale and sandstone above, with beds of coal.

In Westphalia there are black shales below, passing up into black limestones, and those into lighter-coloured limestone, which are covered by black shales and sandstone, in which beds of coal occur.

In Russia there are, according to Sir R. Murchison, two types of the formation.

The northern type consists of (ascending order)—

1. Sands and shales with coal.
2. Dark-grey *Productus** limestone, yellow magnesian limestone, white limestone of Moscow, shale and sandstone, and grey, white, and yellow limestone.
3. Limestones, calcareous grits, and flagstones capped by conglomerate. In this type the coal is confined to the base of the formation.

The southern type consists of—

1. Sands and shales without coal.
2. *Productus* limestone, with shales, sandstones, and thin limestone, with many beds of coal.

* *Productus* is the name of a fossil shell very characteristic of the Carboniferous limestone.

3. Limestone, calcareous grits, and flagstones, with traces of coal, capped by sandstone containing coal-plants. In this type the most coal occurs about the centre of the formation.

In North America the carboniferous formation varies as to its base. In the Illinois district there is a limestone similar to our Mountain Limestone, covered by coal-measures exactly resembling our own; both having a considerable thickness, and spreading over a vast space. In the great Appalachian coal-field, carboniferous limestone forms the base at the southern end, but at the northern the coal-measures rest directly on the Devonian rocks, unless a bed of sandstone and conglomerate should be separated from them under the name of the Millstone Grit. The coal of the Western States is bituminous, but when the coal-measures get involved in the contorted country of the Appalachian chain (or Alleghany Mountains) the coals are found to be all anthracite. In one of the anthracite coal-fields of Pennsylvania (that of Pottsville), "several beds of anthracite, at first widely separated, were brought nearer and nearer together, until they united, and formed one mass, about fifty feet thick*."

* Sir C. Lyell's first Travels in North America, vol. i. p. 85.

In Nova Scotia and the neighbouring colonies, as also on the west side of Newfoundland, the carboniferous formation has a large base, composed principally of red sandstone and marls, with gypsum and brine-springs, over which are coal-measures of very considerable thickness, containing many good beds of coal. Above these, in Nova Scotia, there occurs a group of sandstones and shales, containing fossil plants, but no coal; these however can be looked on only as coal-measures *locally unproductive*. The carboniferous formation of Nova Scotia must have a thickness of many thousand feet.

Coal itself is found in many parts of the world, hardly any large country existing from which it is quite absent. It is at present however uncertain how far many of these coals belong the true carboniferous formations, while as to some of them it is certain that they are of entirely different age. Some of them are Oolitic, others are known to be Tertiary, while some perhaps may be Devonian.

When speaking, at p. 34, of the origin of Aqueous rocks, we deferred the account of the origin of coal to the present place. There is no doubt of all coal being of vegetable origin,—that it is a mass of vegetable matter, the vast accumulation of the *débris* of plants, which, having been some-

how spread over areas of great extent in continuous layers, became covered up by great beds of sand and mud, and thus ultimately squeezed and compacted together, and converted into coal. The nature of the plants is a question for the Palæontologists (or the Palæophytologists) to answer; and they tell us that they were all land-plants, as far as they can be determined at all, and probably plants loving warm and damp situations, marshes, and jungles.

How came the plants however to be accumulated in these thick layers, spreading over many square miles of area, and interstratified in every conceivable way with shales and sandstones? Two methods of explaining this have been proposed.

The first and oldest method supposed the plants to have been drifted into seas, estuaries, or lakes, to have become water-logged and sunk gradually to the bottom, where they were subsequently covered up by accumulations of silt, either mud or sand. The other more recent and now more fashionable supposition is that the plants all, or nearly all, grew where we now find them, forming great swamps and marshes just above the level of the water; that they grew in a region subject to frequent depressions, by which each successive swamp was gradually lowered beneath the water, and that the water was then filled up gradually by sand and

mud being swept into it, till the space became again a marsh, and the process was repeated. This latter hypothesis is supported by the fact of upright stumps of trees being found in the coal; by roots or supposed roots of plants being always or frequently found beneath the beds of coal, in clays which are therefore called "under clays;" and by upright stems of trees being also found in beds of sandstone over the coal, apparently in the position of growth.

All the palæontological evidence indeed goes *at present* to support the hypothesis of the growth *in situ* origin of coal; nevertheless there are certain facts and appearances of structure and of grouping of coal-beds with rocks of undoubtedly mechanical origin, calculated to make a geologist pause before he accept this hypothesis as a true theory; and though it may appear impertinent to speak of my own opinion, I am bound to confess that I have never succeeded in thoroughly satisfying my own mind of the truth of this hypothesis, unless it could be so far modified as to suppose the plants now in their place of growth to have *grown under the water*, and often to have been rooted at a depth many yards below its surface. This however is a question not adapted for discussion in an elementary work like the present, nor is there room for it if it were.

5. THE PERMIAN FORMATION.

We come now to a set of rocks the type of which must be sought out of the British Islands. The name is derived from a Russian district called Perm, where these rocks are very extensively developed. They are there composed of a series of sandstones and marls with interstratified limestones and beds of conglomerate; some of the beds containing copper largely disseminated through them, and others having gypsum and salt-springs associated with them. The prevailing colour is red, but some of the limestones are quite white, and the marls are mottled. The limestones are often magnesian, but not more so than those of the subjacent carboniferous limestones of Russia. Thin beds of coal likewise occur. (Murchison's 'Russia.')

In Germany and in the North of England the Permian rocks are composed of three groups:—

1. The Lower Red Sandstone.
2. The Magnesian Limestone.
3. The Upper Red Sandstone (occasional).

Those of the North of England were fully described by Professor Sedgwick nearly twenty years ago*.

* Transactions of the Geological Society of London, vol. iii. 2nd series.

1. The Lower Red Sandstone of the North of England is a variable group of sands, sandstones, marls, and conglomerates; the prevailing colour of which is red or purple, but they are often brown, yellow, white, or mottled. Their thickness apparently never exceeds 200 feet.

These have been identified with a similar set of beds of red sandstones and conglomerates, underlying the Magnesian Limestone of Germany, and called there "Roth-todt-liegendes."

2. The Magnesian Limestone of the North of England is composed of the following stages, according to Professor Sedgwick (ascending order):—

A. Marl slate, associated with grey, thin-bedded, and nearly compact limestone. 60 feet.

B. A great deposit of yellow magnesian limestone, often cellular and earthy, sometimes hard and crystalline. 500 feet.

C. Red marl and gypsum (lower). 100 feet.

D. Grey thin-bedded limestone. 80 feet.

How far any part of the overlying deposits of red sandstone may belong to the Permian formation in the North of England, is not yet known. Sir R. Murchison says that in Germany some of the red sandstone above the Magnesian

Limestone there, and hitherto classed as Bunter Sandstein, does belong to the Permian.

The true Permian rocks of the North-east of England cannot be directly connected with those of any other part of the country, because they thin out as they range southwards, and are overlapped and concealed by the superior rocks. Both Professor Sedgwick and Sir R. Murchison have however pointed to certain red sandstones in the midland counties as probably representatives of the Lower Red Sandstone of Durham and Yorkshire. This idea has been confirmed and extended by the Geological Survey of Great Britain during the last two years; and certain large masses of red, pale red, and white sandstones, with interstratified deep red marls, and grey mottled marls, with, in one instance, a thin bed of coal and fire-clay, have been separated from the other red sandstones of those counties, and classed as the Lower Red Sandstone of Sedgwick, or the Permian of Murchison. In Staffordshire these Lower Red Sandstones are believed to be unconformable to the coal-measures below them, and to the New Red Sandstone above them. In South Staffordshire and Shropshire, one of the most remarkable members of these Permian rocks is a thick mass of breccia, of large and angular pieces of rock, prin-

cipally different kinds of trap. So large, angular, and close together were these fragments of trap, that it was for a long time believed they were only the local *débris* of actual trap-pean masses *in situ* below,—a belief which was only slowly and after much examination discarded by Professor Ramsay and myself, after completing the survey of the Clent Hills and the neighbourhood.

The thickness of the Permian rocks of South Staffordshire is believed to be upwards of 1500 feet*.

We may suppose that they either represent the Lower Red Sandstone of the North of England very largely developed, or perhaps, with more probability, that some of the coarse mechanical beds of the midland counties were contemporaneous with the finer-grained partly mechanical and partly chemically-formed beds of the Magnesian Limestone. On the latter supposition, we may take the *whole* of the Permian beds of the midland counties as contemporaneous with the *whole* of those of the North of England, without endeavouring to seek among the few small calcareous portions of the former the exact equivalents of the large calcareous masses of the latter.

* See, for more full details as to these rocks, the Maps of Staffordshire and Shropshire, and the Memoir on the Geology of South Staffordshire, just published in the 'Records of the School of Mines,' etc., vol. i. part 2.

CHAPTER XIII.

THE SECONDARY OR MESOZOIC CLASS.

6. THE TRIASSIC FORMATION*.

For the best type of this group also we have to go abroad, into Germany, where it consists of three members:—

1. The Bunter Sandstein.
2. The Muschelkalk.
3. The Keuper.

1. The Bunter Sandstein, a red or variegated sandstone, is in Germany composed of red sandstone, sometimes becoming white, interstratified with red marls and thin bands of limestone, the latter of which is sometimes oolitic, some-

* This is a very badly-chosen name. Trias is apparently a word adopted partly to represent the local accident of its threefold division, and partly in order to rhyme with Lias.

times magnesian. It attains a maximum thickness of 1000 feet.

2. The Muschelkalk, or Shell Limestone, is a compact grey limestone, full of peculiar fossils: it is in places magnesian, and is said also to contain occasionally gypsum and rock-salt. Its thickness is about 300 feet, according to M. E. de Beaumont.

This group has no representative in the British Islands, and it is the only important known member of the secondary class of aqueous rocks of which this can be said.

3. The Keuper, of Würtemberg, consists of sandstones, with bituminous shale and gypsum. That of the Vosges is composed of red, green, and grey marls, with black shales, grey sandstone, and limestone. It contains some beds of coal, and also gypsum and rock-salt, and is said to be sometimes 1000 feet thick.

In the British Islands it is not easy to draw any boundary-lines in the Trias or New Red Sandstone. Its lower part generally consists of thick bright red sandstone, occasionally containing large accumulations of quartzose conglomerate, which is often so incoherent as to be called gravel, and mistaken for superficial drift; over this is commonly a brown sandstone, interstratified with bands of marl,

and occasionally with calcareous concretionary sandstones, like the cornstones of the Old Red; these again pass upwards into a great series of marls, commonly red or variegated, interstratified with some red sandstones, and containing beds of rock-salt and gypsum. Some of these beds of salt, as near Northwich, in Cheshire, and Carrickfergus*, in Ireland, are seventy and eighty feet thick, and in each of these localities two of these beds occur, with but a small thickness of marl between them. Some beds of gypsum are twenty-five feet thick.

It is usual to separate the New Red Sandstone of England into two groups:—

1. The Red and Variegated Sandstone and Conglomerate: probable thickness 1000 feet.

2. The Red and Variegated Marls: probable thickness 1000 feet.

In the upper part of the marls a band of dove-coloured sandstone has been found, in the central parts of England,

* The rock-salt of Carrickfergus has recently been discovered by the enterprise of the Marquis of Downshire. There are two beds, making together a thickness of more than 120 feet, and lying under 630 feet of red marl, with some gypsum. There is also a good thickness of marl still higher than the top of the shaft.

to contain fossils, identifying it with the Keuper of Germany.

7. THE OOLITIC FORMATION.

For the best type of this important system of rocks we must return to England, where it is admirably exhibited. It was first worked out by Dr. William Smith.

It was called Oolitic, because many of its limestone beds were oolite, or roe-stone (see p. 52) ; and the term has been extended, with a technical signification, to the whole system, from a character thus possessed by some of its most conspicuous portions.

In the South of England it can be divided into the following groups :—

- A.* The Lias.
- B.* The Lower Oolite.
- C.* The Middle, or Coralline Oolite.
- D.* The Upper Oolite.
- E.* The Purbeck group.

These groups are again subdivided into stages or sets of beds, as follows :—

<i>A. Lias</i>	{	1. Lower Lias Shale and Limestone.
		2. Middle Lias Shale.
		3. Marlstone.
		4. Upper Lias Shale.
<i>B. Lower Oolite</i>	{	5. Inferior Oolite Sand.
		6. Inferior Oolite.
		7. Fullers' Earth.
		8. Great Oolite.
		9. Forest Marble and Bradford Clay.
		10. Cornbrash.
<i>C. Middle Oolite</i>	{	11. Kelloways Rock.
		12. Oxford Clay.
		13. Lower Calcareous Grit.
		14. Coral Rag.
		15. Upper Calcareous Grit.
<i>D. Upper Oolite</i>	{	16. Kimmeridge Clay.
		17. Portland Sand.
		18. Portland Oolite.
<i>E. Purbeck Group</i>	{	19. Lower Purbeck Beds.
		20. Middle Purbeck Beds.
		21. Upper Purbeck Beds.

A. The Lias.

The Lower Lias Shale rests immediately on the upper portion of the variegated marls, there being often a gradual, but pretty rapid passage from the red marls of the one to the grey marls of the other. In Needwood Forest, Staffordshire, they are so similar that the lias is simply called

the White Marl. At a distance of only a few feet above the base of the formation come in some thin bands of pale limestone, of a peculiar character, making hydraulic lime. These are quite constant over all the central parts of England. They are worked at Barrow-on-Soar, in Leicestershire, and other places.

Above these comes the Middle Lias Shale, a compact grey clunch, more or less finely laminated.

Over this is the Marlstone, a set of beds of dull brown colour, which might often be called a calcareo-argillaceous sandstone. It is 220 feet thick in some places.

Above the Marlstone is the Upper Lias Shale, not differing in any important character from the Middle Lias Shale.

The total thickness of the Lias group in all the central parts of England is between 400 and 500 feet.

B. The Lower Oolite.

Upon the upper part of the Lias is often found a dark brown and rather incoherent sand, upwards of fifty feet thick. Over that comes a set of beds of about equal thickness, consisting of coarse calcareous sandstones and coarse shelly limestones, mingled with finer-grained beds both of sandstone and limestone, some of the latter being oolitic.

Hullmandel & Walton Lith.

C. V. Du Noyer, del.

CLEVELAND IN GREY STATE, RINGBELL LA BAY, CO. CORN.

These beds often exhibit the structure called oblique lamination. (See Plate VIII.)

Above the Inferior Oolite is sometimes, but not always, found an argillaceous band, 130 feet thick, which, from its being used in the fulling-mills of Gloucestershire, acquired the name of the Fullers' Earth.

Over this, or where it is not present, over the Inferior Oolite, we have the Great Oolite, so called from its showing the thickest and largest mass of fine-grained oolitic limestone of the whole system. Part of it is well known as Bath-stone. The thin calcareous flags, locally known as Stonesfield slate in Oxfordshire, and Collyweston slate in Northamptonshire, are at the base of the Great Oolite. The total thickness of the Great Oolite series is 130 feet.

Over the Great Oolite we get thin beds of hard shelly limestone, some of which admit of a polish, and from this circumstance, and their occurring at Whichwood Forest, in Oxfordshire, it has acquired the name of the Forest Marble. The beds are often interstratified with partings of clay, some of which thicken out, at Bradford, in Wiltshire, to about sixty feet, and were celebrated, under the name of the Bradford clay, for the beautiful fossils they contained. The total thickness of the Forest Marble does not usually exceed 30 to 50 feet.

The upper beds of the Forest Marble become sandy, and it passes upwards into a set of clays and calcareous sandstones and rubbly limestones, which, being locally known under the name of Cornbrash, were generally designated so by Dr. William Smith. The Cornbrash is from 16 to 30 feet thick.

The total thickness of this series of oolitic and shelly limestones, calcareous sandstones, clays, and sands, called the Lower Oolite, may be stated as between four and five hundred feet in the centre and south of England.

C. The Middle Oolite.

Over the upper bed of the Lower Oolite, whatever it may be, is invariably found a great mass of dark-blue tenacious clay, called the Oxford Clay, in the bottom part of which are in some localities some dull grey beds of argillaceous limestone, called Kelloway rock, from their being first noticed near Kelloway bridge, in Wiltshire. The Oxford Clay has a maximum thickness of probably 700 feet. It is a pretty uniform mass throughout, with the exception of the Kelloway rock below, and some local beds of brown arenaceous limestones that sometimes occur near its upper portion.

The Oxford Clay is crowned by a series of beds commonly called the Coral Rag, from the abundance of fossil corals they contain. This is a very coarse brown limestone, in some places almost entirely composed of large corals*. It has above and below it, in Yorkshire, coarse mechanical-looking limestones, called the Upper and Lower Calcareous Grit. The thickness of this Coral Rag stage is from 150 to 200 feet.

D. The Upper Oolite.

Above the Coral Rag beds we have another thick mass of clay, often not to be distinguished by any mineral character from the Oxford Clay; and where the Coral Rag is absent, as it is in Cambridgeshire for the most part, the two clays form one continuous and undistinguishable series of beds. Towards Kimmeridge, in Wiltshire, this clay becomes much more bituminous and carbonaceous, and contains sometimes

* It is commonly said that this is a fossil coral-reef. It certainly resembles a coral-reef in a shallow and sheltered sea, but bears no resemblance to the huge atolls, or barrier reefs, rising abruptly from water 1000 to 2000 feet deep, and which must therefore have that thickness, at their outward edge at least. While sailing within the Great Barrier Reef of Australia, in twenty fathoms water, among sheltered reefs, I was often struck with the resemblance in the stuff brought up by the anchor to the coarse limestones of the Oolitic system.

thin beds of impure coal. It has altogether a thickness which is said sometimes to equal 600 feet.

Above the clay is found a bed of brown compact sand, over which is the Portland-stone, well-known as a building stone, and quarried largely in the Isle of Portland. It is there a fine-grained oolitic limestone, having that peculiar equableness of texture in all directions, which constitutes a "free-stone." Its thickness, together with that of the Portland-sand below, is about 120 feet.

E. The Purbeck Group.

The Purbeck beds are best seen in the peninsula called the Isle of Purbeck, in Dorsetshire. They consist of limestones, (often taking a polish and called Purbeck marble,) marls, and calcareous flags*.

My colleague Professor Edward Forbes has lately thrown much and interesting light on the palæontology of the Purbeck beds, showing that they ought, though only 150 feet thick, to be subdivided into Upper, Middle, and Lower, each subdivision being characterized by peculiar fossils,

* These are often spoken of as calcareous "slates," a term which, however locally in use, should be always discouraged by Geologists, as Slate should always be confined to the superinduced structure of true slaty cleavage.

mostly fresh-water, but some of them brackish-water, and one band consisting of marine fossils.

The Lower Purbeck beds contain some very interesting and important beds, well known to geologists under the name of "dirt-beds," being old vegetable soils.

On the top of the Portland-stone, in the Isle of Portland, lie about eight feet of fresh-water limestone, on which rests a bed a foot or a foot and a half thick, called the "dirt-bed" by the quarrymen, full of the erect stumps and fallen stems of trees and erect stools of plants called Cycadeæ, with rounded stones dispersed at intervals. It is the vegetable soil and the fossil remains of an old forest, which has been depressed below water so tranquilly as not to have been disturbed or washed away. Near Lulworth this is covered by thirty feet of marls formed in brackish water, over which is about forty feet more marl of purely fresh-water origin. These beds altogether compose Professor Forbes's Lower Purbeck : 80 feet thick.

Over them come his Middle Purbeck, 30 feet thick, having a base of green shale, over which are fresh-water beds with chert ; a bed of oysters, called the Cinderbed ; over which are brackish and fresh-water beds, with one purely marine. The Upper Purbeck is entirely fresh-water,

consisting of marls and limestones: altogether 50 feet thick.

Although the absolute thickness of the deposits of these Purbeck beds is so insignificant, yet when we take into account the changes of condition exhibited in them from sea to fresh water, from fresh water to dry land, from dry land again to estuary, fresh water, brackish water, sea, and again fresh water, and take into account that each set of beds is characterized by a different set of fossils, showing the species of animals to have been several times changed over this district, it is probable that we have here the record of a lapse of time as great as would have sufficed under other circumstances for the accumulation of a vast thickness of beds. It is probable therefore that in some part of the globe such an accumulation may be found.

Having now got this complete type of the Oolitic system, we should be able to follow it into other districts, and mark its gradual and successive changes, without any confusion being produced in our minds. If we were to follow it into Yorkshire, we should find the Lower Oolite group swelling out into a great series of sandstones and shales with some interstratified oolitic limestones, containing many fossil plants and some good beds of workable coal and beds of

ironstone. It is in fact an oolitic coal-field, having a thickness of more than 800 feet. The same beds, or nearly the same, occur again at Brora in Sutherlandshire, where one coal-bed is three feet six inches thick, with several others of inferior quality.

If we were to follow the system in another direction, namely to the south-east, through France to the flanks of the Alps, we should find a change of another character taking place. The clays gradually thin out and disappear, while the limestones thicken and become more prominent, some being oolitic, but others compact, shelly, and flaggy; some argillaceous and marly limestones being supposed to represent the great Kimmeridge and Oxford clays*. Notwithstanding this entire change in mineral character, it is said that the three great divisions of Upper, Middle, and Lower can be recognized by the characteristic fossils, which are the same as those of England.

The Lias seems to retain its mineral characters pretty well unaltered into the heart of Europe, where it is said to have the oolitic rocks resting unconformably on it. It

* From the mountain-chain of the Jura being chiefly composed of these calcareous masses belonging to the Oolitic formation, the term Jurassic is often used to designate it, as a synonym of Oolitic.

certainly retains its characters throughout the whole of the British Islands.

Coal-fields belonging to the Oolitic period are known both in North America and in India, their identity being made out by the fossils contained in them. Sir Charles Lyell says that in the oolitic coal-field of Richmond, in Virginia, he descended a shaft 800 feet deep, into a bed of coal (probably a set of beds) forty feet thick; the coal being fully equal in quality to the finest bituminous coal of our fields in the Carboniferous system.

8. THE WEALDEN AND NEOCOMIAN FORMATIONS.

It has been customary hitherto to class the Purbeck group with the Wealden; and the Neocomian, under the title of the Lower Greensand, with the Cretaceous formation. Professor Forbes however informs me that palæontologically the Purbecks belong to the Oolites, and the Lower Greensand to the Wealden. So far as pure physical geology is concerned, I believe it matters not at present where the boundaries are drawn; and if the palæontological data be well founded, future discoveries will probably show that lithological or physical characters and structure agree with them.

This subdivision then will now consist of three groups or formations :—

- A.* The Hastings Sand.
- B.* The Weald Clay.
- C.* The Lower Greensand.

A. The Hastings Sand.

The Hastings Sand series consists of beds of clay, shale, and ferruginous sandstone in the lower parts, with layers of ironstone; soft friable yellow sandstone in the middle, and grey calcareous sandstone in the upper portions. These lithological characters are liable to considerable variation in different localities, a general arenaceous character being retained. They are principally of fresh-water, but some of brackish-water origin. The maximum thickness of the group is about 500 feet.

B. The Weald Clay.

The base of the Weald Clay series is composed of clays and sands, including a limestone known as the Petworth or Sussex Marble. Over this is a stiff blue clay, with concretionary ironstone, that was formerly worked for smelting-furnaces. This clay becomes sandy above and passes gra-

dually into the green sands of the next superior formation. By the included fossils the Weald Clay is chiefly of fresh-water origin. It varies from 140 to 280 feet in thickness.

C. The Lower Greensand, or Neocomian Group.

In the South-east of England the Weald Clay passes sometimes by an insensible gradation upwards into beds of brown ferruginous sand full of green specks. These green specks are sometimes said to be chloritic earth, sometimes silicate of iron; they occasionally become so abundant as to communicate a decided green tinge to the mass, whence the name. This designation however is technically continued to them even when the sands become brown, yellow, or white. These sands are generally incoherent, but are sometimes compacted together by a calcareous cement into a hard stone called Kentish Rag. They often alternate with beds of clay in their lower part, and the Speeton Clay of Yorkshire is now referred to this group. At Atherfield in the Isle of Wight the thickness of this group has been found to be 840 feet, while on the coast of Kent it is not more than 400.

Beds that have been more or less accurately identified with the Wealden have been described as occurring in the

North of France, in Hanover, in Westphalia, and even in Poland.

The Neocomian group acquires even a greater importance as we trace it through France to the flanks of the Pyrenees and the Alps, than it possesses in England. In the basin of the Seine M. D'Archiac gives the following synopsis of it, dividing it into three stages (*étages*) in ascending order.

FIRST STAGE . . .	{	1. White and ferruginous sands.
	{	2. Neocomian limestone and blue marl.
SECOND STAGE . . .	{	3. Oyster marls.
	{	4. Variegated clays and sands with iron.
THIRD STAGE . . .	{	5. Plicatula marls.
	{	6. Green and ferruginous sands.

The total thickness being not greater than 150 to 200 feet.

Further south however, as for instance in Switzerland, on the flanks of the Jura, where the Neocomian* beds are said to repose *unconformably* on the Upper Oolites, single portions of them are described as limestones 130 feet thick interstratified with blue marls 32 feet thick. M. D'Archiac says, that while his first and third stages are still comparable in the North and South of France, "the second, in Provence, in Dauphiny, and Savoy, shows a strength and characters altogether peculiar," and that the whole group ac-

* Neocomian is *Neocomiensis*, or the rock of Neufchâtel.

quires a development far superior to anything it has in England or the North of France.

9. THE CRETACEOUS FORMATION.

Having separated the Lower Greensand from this formation, we have it now composed of the following subdivisions, or series, groups, and stages of beds:—

<i>A.</i> The Gault.	(One group, containing one stage.)	
<i>B.</i> The Greensand (Upper).	(Ditto, ditto.)	
<i>C.</i> The Chalk Marl.		} One group of three stages.
<i>D.</i> The Chalk without flints.		
<i>E.</i> The Chalk with flints.		
<i>F.</i> The Maestricht beds.	(Group of two stages.)	

A. The Gault, a dark blue clay, is never more than about 100 feet thick. It occurs occasionally in the south-east of England, and can be traced here and there through France to the flanks of the Alps, and even into Bavaria.

B. Over the Gault is the Upper Greensand, which likewise never (in England) exceeds 100 feet in thickness. Lithologically it resembles the Lower Greensand, and contains similar beds of calcareous grit, sometimes called fire-stone. Its fossils however, as well as those of the Gault, differ from

those of the Lower Greensand. It often contains nodules of chert and bands of siliceous limestone. Some of the fossil contents of the Lower Greensand and Gault become of lithological importance; these are small black nodules containing phosphate of lime, and thus useful as a manure: they are believed to be the fossil excrement (or coprolite) of fishes. The Upper Greensand often thins out to a mere seam, and passes upwards, if not laterally, into some dull greenish or bluish or pale dove-coloured marl, which is the lower part of

C. The Chalk Marl.—The Chalk Marl becomes sometimes a soft argillaceous limestone, and is used for a building stone in Cambridgeshire and other places. It becomes less and less argillaceous as we trace it upwards, gradually passing into a great mass of pure white chalk.

D. The Chalk without flints.—This earthy pulverulent rock is well known to every one. It is almost a pure carbonate of lime, occurring commonly in very thick beds, the whole being so homogeneous in structure that its stratification is often not easily discernible. Its being split by many irregular joints, the surfaces of which often become discoloured, increases the difficulty of discerning the bedding. It often contains radiated balls or irregularly shaped

lumps and concretions of iron pyrites, which may be detected by the rusty stain in the rock around them. Its maximum thickness varies from 400 to 600 feet.

E. The Chalk with flints is exactly the same sort of rock as that just described, except that it is characterized by containing layers of nodules, and sometimes irregular seams or plates of flints, generally white outside, but black or brown internally. It seems that, as in the case of the mountain and other limestones, the water in which the chalk was deposited contained silica in solution, and that each stratum of soft calcareous mud included a portion of this silica diffused through it, which before the mud consolidated segregated itself and drew together into balls or nodules, often enveloping a sponge or other fossil, which served it as a point of union as it were. The Chalk with flints has a maximum thickness of 400 or 500 feet.

F. The Maestricht beds (seen near Maestricht in Holland) consist of a lower set, passing insensibly into the chalk with flint, containing itself grey flints, while those in stage *E* are black; and an upper set, consisting of a loose yellowish limestone, without flints, and sometimes almost exclusively composed of organic remains. The total thickness of these two stages is about 100 feet. Some of the fossils found in

these beds more nearly resemble those found in Tertiary rocks than do any other secondary fossils. Similar beds, containing similar fossils, occur at Faxoe in the island of Seeland, in Denmark, where they are more than forty feet thick.

Chalk is such a peculiar substance that one is naturally induced to speculate on the method of its formation. Lieutenant Nelson, Mr. Dana, and others have shown that the waste and *débris* derived from coral-reefs produces a substance exactly resembling chalk. I can corroborate this assertion from my own observations, both on some white very chalky limestones in Java and the neighbouring islands, which I believe to be nothing else than raised fringing coral-reefs, and on the substance brought up by the lead over some hundreds of miles in the Indian Archipelago, and along the north and north-east coasts of Australia, and the Coral Sea of Flinders. This was especially observable wherever deep soundings were struck in the openings of the reefs or outside of them, just where the reflux of the tides and currents were carrying out into the open sea the finer sediments derived from the waste of the reefs, the ultimate product of the grinding up of the calcareous sands.

The Cretaceous formation, with the characters here as-

signed to it, spreads over all North-western Europe, and appears in the form of chalk even in Poland and the South of Russia, in which latter district it is said by Sir R. Murchison to be in some places more than 630 feet thick. In other parts of the world rocks belonging to the cretaceous period (as shown by their fossils) exist and are largely developed, but they no longer assume the form of chalk. They are sometimes sands and clays, as in part of the United States ; sometimes even clay-slates, precisely like our Old Silurian rocks in mineral character, as in the southern part of South America.

Geological Survey of the United States

Hullmandel & Walton, Lith

CHAPTER XIV.

TERTIARY OR CAINOZOIC ROCKS.

THE broad distinction between Tertiary and Secondary rocks is a palæontological one. None of the Secondary rocks contain any fossil animals or plants of the *same species* as any of those living at the present day*. Every one of the Tertiary groups *do* contain some fossil animals or plants of the *same species* as those now living.

This doctrine of approximation to living forms was carried out by Sir C. Lyell into the further use of separating and classifying the Tertiary rocks themselves. He arranged them in a chronological series, according to the *percentage*

* This statement will not be practically invalidated by the fact, if it be one, of certain minute *Foraminiferæ* (small polype-like animals making microscopic shells) being found fossil in the uppermost Secondary rocks, and alive in the present seas.

of living forms met with among the fossil *shells* found in the different Groups, Formations, or Systems. The lowest or oldest division he called Eocene, from two Greek words signifying "the dawn of the recent," this system of rocks containing only from 2 to 5 per cent. of living forms. The next division he called Miocene, signifying the "minor proportion of the recent," containing from 18 to 25 per cent. of living forms. The third division is the Pleiocene, or the "major proportion of the recent," containing from 30 to 50 per cent. of living forms. Of this group there is a subdivision called Pleistocene, or the "maximum proportion of the recent," containing from 90 to 95 per cent. of existing forms. After these comes a still more recent group, called the Post-Pleiocene, or by some the Quaternary, in which all the fossil shells are still found living on the globe, though not always perhaps in the immediate neighbourhood of the places where they are found fossil.

The necessity of some method of testing the relative age of the Tertiary class of rocks independent of superposition, arose from the fact that in Europe (and in most other parts of the world) the several Tertiary formations are not so widely spread and continuous as those of the Primary and Secondary class. They occupy extensive but still iso-

lated districts, so that the rocks of one region can be but seldom traced continuously into another, and their relative position in the vertical scale actually observed.

10. THE EOCENE SYSTEM.

In the British Islands strata belonging to this system are found only in the south-eastern parts of England, namely, in the country around London, and in the south of Hampshire and the north of the Isle of Wight. They consist of the following groups and stages of beds* :—

		FEET.
LOWER EOCENE	{ <i>A.</i> Plastic Clay, Woolwich beds, Thanet Sands . .	150
	{ <i>B.</i> London Clay and Bognor rock, fresh-water . .	350
MIDDLE EOCENE	{ <i>C.</i> Bagshot and Bracklesham Sands, marine . . .	700
	{ <i>D.</i> Barton Clays, marine	300
	{ <i>E.</i> Headon fluvio-marine and fresh-water series .	180
UPPER EOCENE	{ <i>F.</i> St. Helen's Sands	100
	{ <i>G.</i> Bembridge series	120
	{ <i>H.</i> Hempstead series	170

The surface of the chalk in many parts of the South-east

* This classification of the English Eocene beds, as to the two lower portions, is that of Mr. Prestwich, who has surveyed them with great zeal and industry during the last ten years. The upper portion is the result of the recent discoveries of Professor Edward Forbes.

of England is found to be greatly worn and eroded into pits and hollows, with occasional crags and pinnacles of chalk projecting from it. This uneven surface is generally covered by great beds of sand and gravel, the pebbles of which are invariably rolled flints derived from the destruction of the chalk. Some of these beds of sand and gravel may have been removed and redeposited in more recent times, but some of them, especially round the margins of the Hampshire and London districts before spoken of, were accumulated at, and have been left undisturbed since, the commencement of the Eocene epoch.

A. These gravels in many places form the base of the Plastic Clay beds, but in others, as in the Isle of Thanet, certain sands compose their base. Over these are certain beds of finer sand and beds of blue or whitish clay, containing marine and estuary shells. These clays are often used for bricks, and in some places for pottery; hence the term Plastic Clay, originally assigned to the Lower Eocene beds in France, was adopted in England, and extended technically to the whole set of beds, whether clays or gravels. The maximum thickness of the Plastic Clay beds may be stated at 150 feet.

B. Above the Plastic Clay beds is a thick mass of dark

brown and blue clay, full of marine shells and fossils, called the London Clay. It often contains large nodular calcareous concretions, called *Septaria*. In some places, as near Bognor in Sussex, are some masses of light-coloured calcareous sandstone, called the Bognor rock, likewise full of marine shells. The total maximum thickness of the London Clay may be stated at 350 feet.

C. Over the London Clay occur certain accumulations of sand with some clays, likewise containing marine fossils, which, from their occurring around Bagshot in Surrey and Bracklesham Bay in Sussex, are called Bagshot sands and Bracklesham sands and clays. Their thickness is believed to be about 700 feet.

D. Above these, it is believed, come the Barton beds, containing marine fossils, and consisting principally of clay. Their thickness may be stated at 300 feet.

E. Over the Barton beds there occurs, in the northern part of the Isle of Wight and the coasts of Hampshire, a great series of marls, clays, and sands, with some soft, rather silicious limestone, containing shells, such as are found in fresh-water lakes, and in rivers and estuaries. These were formerly all grouped together as the Headon Hill beds, and were assigned a thickness of about 200 or 300 feet; they

have however been carefully examined and surveyed lately by my eminent colleague, Professor Edward Forbes, and have been found by him to be capped by an equal thickness of similar fresh-water and estuary strata, which contain a different set of fossils from those below them, and belong to a different and newer part of the Tertiary series, being in fact the equivalents of the Upper Eocene or Lower Miocene of Continental geologists. He has accordingly limited the group *E*, and added above it the three groups *F*, *G*, *H*, as shown in the preceding synoptical table.

The best-developed and most thoroughly investigated series of Eocene rocks out of the British Islands, are those of the neighbourhood of Paris.

The Eocene beds of the Paris basin, as it is called, are divided into several groups, more or less strictly contemporaneous with those already described. According to M. D'Archiac they consist of—

	FEET.
<i>A.</i> Sables Inférieurs	160
<i>B.</i> Calcaire Grossier	100
<i>C.</i> Grès et Sables Moyens	50
<i>D.</i> Calcaire Silicieux, ou Calcaire Lacustre Moyen	196
<i>E.</i> Grès et Sables Supérieurs	80
<i>F.</i> Calcaire Lacustre Supérieur	40*

* Mr. Prestwich assigns to Group *A*, "Sables Inférieurs," a thickness of

A. On the uneven and worn surface of the French chalk, as on that of England, are found the lowest beds of the Eocene System. M. D'Archiac divides this group into several "*étages*," as follows:—*a.* Conglomerates, clays, lower fresh-water limestone, and lower "glaucanie." *b.* Plastic clay, lignite, fresh-water marls, oyster-beds, and "glaise sableuse." *c.* Grits, conglomerates, and shelly sands. *d.* Various sands, or "glaucanie moyenne." *e.* Shelly beds. *f.* "Glaise et sables glauconieux."

B. Over these come the group of the Calcaire Grossier, divided into four stages of—*a.*, lower; *b.*, middle; *c.*, upper; and a capping of, *d.*, marls.

C. This group is divided into three stages:—*a.* Sables; *b.* Grès; *c.* Marine limestone.

180 feet, making it correspond in age with the Plastic Clay and London Clay groups of the English Eocene System. The "Calcaire Grossier" he considers the French representatives of his English groups *C*, *D*, *E*, viz. the Bagshot, Bracklesham, Barton, and Headon beds. The upper French groups were believed to be unrepresented in England till last autumn, when Professor Edward Forbes discovered his three newer groups, that had been hitherto overlooked and confounded with the beds below. He identifies his

St. Helen's Sands with the Grès et Sables Moyens;

Bembridge Series with Calcaire d'eau douce Inférieur;

Hempstead Series with Grès et Sables Supérieurs;

leaving only the uppermost group, the Calcaire Lacustre Supérieur, unrepresented in Britain.

D. The lower fresh-water limestone group has five stages :
a. Marls and marly limestones. *b.* Gypsum and gypseous marls. *c.* Green marls and marly limestone. *d.* Marls and marly limestone, with kidney-shaped nodules of flint. *e.* Clay and “meulière.”

E. This group has three stages :—*a.* Marine marls. *b.* Sands and beds of shells. *c.* Fontainebleau sandstone.

F. The upper fresh-water limestone is divided into two stages :—*a.* Clay, limestones, and lacustrine marls ; and, *b.* a *Helix* limestone, or “Calcaire de l’Orléannais.”

M. D’Archiac gives a detailed section, taken near Pavant, on the left bank of the Marne River, in which the four first groups are seen reposing on each other. From their thickness, together with that of the superior beds in the neighbourhood, and the depth of the artesian well of Reuil, he assigns a total thickness of 200 metres = 656 feet English, to the Eocene beds of this part of France. The gypseous beds in Group *D* are celebrated as those from which Cuvier derived the fragments of that wonderful series of fossil quadupeds which he may be said to have restored to existence ; they are quarried largely in the hill of Montmartre, for Plaster of Paris.

In Central France, in the Auvergne, Cantal, and Velay,

are very thick and important formations, entirely of fresh-water origin, the deposits of old lakes, which are believed to be of the age of the Upper Eocene beds. Sir C. Lyell describes them as consisting of irregularly alternating beds of sand, sandstone, clay, marl, and limestone. Single sets of these beds, as for instance some green and foliated marls, exceed 700 feet in thickness, made up of laminæ of marl not thicker than paper, containing between each two laminæ countless myriads of the small foliaceous shells of an animal called *Cypris*. This little animal moults its shells periodically, and it helps to give us some notion of the lapse of geological time, when we see strata made up of the thinnest possible sheets of the results of these periodical moultings, each separated by the thinnest film of earthy sediment, yet forming an aggregate thickness of rock of many hundred feet.

The same lesson is given us by the "indusial limestone" of these districts, a limestone, single beds of which are six feet in thickness, yet almost entirely made up of the indusia, or cases, of eaddis-worms, ten or twelve of which can be packed within the compass of a cubic inch*.

Another instructive lesson is afforded us from the same

* Lyell's Elements, p. 184 *et seq.*

district, by finding some of the red and variegated marls undistinguishable by any lithological characters from the New Red Sandstone and Marls of the base of the Secondary series, showing us how very uncertain a guide may be lithological character, if it be not confirmed by palæontological evidence, or by the clearest circumstances of superposition.

The Nummulitic limestone of the Alps, a formation which stretches through all the countries surrounding the Mediterranean, and thence through Lower Asia into India, and which is many thousands of feet in thickness in some places, has been shown by Sir R. Murchison to be clearly referrible to the Eocene period.

11. THE MEIOCENE FORMATIONS.

If we class with the Eocene system those beds which have by some authors been called Lower Miocene, and by others Upper Eocene, it would appear that there are very few important deposits at present known which we can class under the head of Miocene. Incoherent beds of sand and gravel, with shells called “faluns,” in Touraine, not thicker than fifty feet; other beds, near Bordeaux, and some in Piedmont, as also a thick formation of soft green

sandstone, called *molasse*, in Switzerland, are referred by Sir C. Lyell, with more or less of certainty, to this division of the Stratigraphical Series. He also assigns to it some sands in Belgium, about twenty or thirty feet thick, called the Bolderburg Sands.

Inasmuch as there is a considerable gap however in the Palæontological series between any Eocene and any Pleiocene beds, it appears probable that it will ultimately be filled up by the discovery, in some part or other of the world, of more large and important formations of the Meiocene period.

12. THE PLEIOCENE FORMATIONS.

These rocks are subdivided into two—Older Pleiocene and Newer Pleiocene, or Pleistocene.

Of the Older Pleiocene we have in the British Islands a representative in the Crag of Suffolk.

The Crag consists of two portions, groups, or stages, namely, Red Crag and Coralline Crag. The Coralline Crag, which is the older of the two, is a mass of soft marly sands of a white colour, with occasional bands of flaggy limestone. In some places it is fifty feet thick, but rarely exceeds twenty in others. Near Ipswich it is seen to have suffered denu-

dation and to have been worn into hollows bounded by little cliffs, with the beds of the Red Crag filling up the hollows and abutting against the cliffs. The Red Crag is composed of red quartzose sand, and accumulations of rolled shells; it is not often thicker than forty feet. Thin beds of sand containing the same fossils as those of the Suffolk Crag occur in Belgium, in the country around Antwerp*.

Although these strata are thus thin and insignificant, and of comparatively slight importance to the geologist, they are of great interest to the palæontologist, as containing a large assemblage of fossils, many of which are still living in our own seas, or those around Spain, and in the Mediterranean.

The deductions of the palæontologist become likewise of interest to the geologist, because they prove to him the lapse of a great period of time beyond that marked by the actual deposition of materials in our own district, and prepare him for the existence in other parts of the globe of large accumulations of rocks formed during this interval of time.

Some of these accumulations are found in Italy, forming the low hills intervening on each side between the Apennines and the sea, and known to geologists by the term

* Lyell, *Journal of the Geological Society*, vol. viii.

Subapennines.' They are composed of brown and blue marls, sometimes micaceous, and often very calcareous, which in some places, as near Parma, are upwards of 2000 feet thick, over which are yellow sands and conglomerates.

The seven hills of Rome are composed partly of these marine strata, and partly of very recent calcareous tufa, now 200 feet above the Tiber, but which must have been formed in a marsh*; so that, though geologically most recent, it is historically of an age long anterior to the building of Rome.

13. NEWER PLEIOCENE OR PLEISTOCENE BEDS.

Near Norwich there occur some crag beds consisting of sand, loam, and gravel, which, from the fossils they contain, are decided by Sir C. Lyell to be much newer than the Suffolk Crag. They are about 40 or 50 feet thick in some parts.

In Sicily beds of this age cover nearly half the island, and reach an elevation of 3000 feet above the sea. Their lower portion consists of blue marl, clay, sandstone, and conglomerate, which, with interstratified beds of volcanic

* Lyell's Elements, p. 168, 4th edition.

sand and ashes, forming tuff, have an aggregate thickness of 2000 feet. The upper part is composed of a limestone sometimes as compact as marble, sometimes coarse and porous, which attains a thickness of 700 or 800 feet. The whole is crowded with marine shells and fossils, a very large proportion of which still inhabit the Mediterranean; a few are not now known in that sea, but are found living in others, while a small percentage are not known to be now living anywhere upon the globe.

CHAPTER XV.

POST-PLEIOCENE, OR QUATERNARY FORMATIONS.—THE
MODERN OR HUMAN PERIOD.

WE have hitherto said nothing of climate, or of the temperature, either of particular parts or of the general surface of the globe. Had we endeavoured to describe the palæontological part of Geology, we should have met with frequent evidence of the probable existence of a higher temperature in the extra-tropical regions of the earth than now belongs to them. This would be more or less the case down even to the most recent of the Pleiocene formations, many of the fossils of which would appear to have required a higher rather than a lower temperature than that now prevailing in the latitudes where they are found.

In examining the Post-Pleiocene formations however

palæontologically, we should soon meet with evidence of a state of things the very reverse of that mentioned above; the fossils found in them, in the British Islands and neighbouring countries, being, many of them, such as are now only found in more Arctic regions.

This fact enables us to explain many appearances on the surfaces of hard rocks (of whatever age or character) immediately beneath the Post-Pleiocene formations, or similar appearances now uncovered and which perhaps have remained so during the Post-Pleiocene period. These appearances consist of polished surfaces, of grooves, mouldings, scratches, and striæ. They are just such as might be caused by large masses of ice, sliding over the surface of hard rock, either above water, as glaciers on hill-sides or slopes, or as icebergs, grounding on the bottom of shallow water. The ice may either have been pure ice, or may have contained large or small masses of rock frozen in it, which have acted as gravers, chisels, and planing tools. In addition to ice however, Mr. Mallet has acutely pointed out that many of these appearances may be due to what he somewhat inappropriately terms "mud glaciers," by which he means the sliding forward or slipping of great masses of clay, mud, or sand, charged with pebbles and boulders,

G. V. D. Noyer. del.

Hellmuth & Walton Lith.

MATLOCK AND WILLERSLEY CASTLE, DERBYSHIRE.

along the inland surfaces of rock, either as the land rose from the sea, or when they were subsequently loosened by the action of rain and other water.

The Post-Pleiocene formations generally consist of irregular deposits of clay, sand, and gravel, with which, in many instances, are associated huge blocks of rock that have been transported sometimes from vast distances. In some districts, as in the south-east of Ireland, in the Isle of Man, in parts of Scotland, and in Holderness on the coast of Yorkshire, these deposits are more regular. Beds of clay or marl 50 or 60 feet thick spread for great distances and with great evenness over the low lands, capped probably by regularly stratified deposits of sand, and these covered by gravel and boulders; the whole having a thickness of upwards 100 feet, and equalling many of the older Tertiary formations in importance. The boulders associated with these beds vary in size from mere pebbles up to blocks many tons weight, or even as big as cottages. They have been transported from Norway and Sweden to the plains of Germany, or from Scotland and Cumberland to the centre and south of England, or from the north of Ireland to the south. They have been carried across intervening seas, valleys, and hills, in such a way as to render it necessary to

suppose that they have been floated across them by being frozen into icebergs, which, as they drifted southwards, melted and dropped them on the districts where they are now found, when those districts were under the waters of the sea. The icebergs may have drifted in many directions, but would only melt and part with their enclosed blocks as they floated nearer to the equator, which will account for blocks having been almost invariably transported (though not quite invariably) from north to south over the temperate and Arctic regions of Europe and North America. Icebergs have been seen in our own days, both in the northern and southern hemispheres, laden with mud, sand, gravel, and blocks of rock, which, as they drifted from the polar regions towards the equator and gradually melted away, they must necessarily have dropped to the bottom of our present seas.

Marine shells of an Arctic character have been found on our present mountains to a height of 1400 feet above the sea (Moel Tryfan in Caernarvonshire), showing how much lower our present lands were then than now*. Our loftiest mountains would then have been small islets, and on some

* Professor Ramsay extends this depression of the land to a depth in some instances of 2300 feet below its present level.—*Geological Journal*, Aug. 1852.

of them, as for instance on Snowdon, distinct traces may be seen of glaciers having formed in their valleys and ravines and slid down them towards their foot, grooving and polishing the rocks, and depositing piles of "moraine," or rough detritus, just as the Swiss glaciers do now.

In some places in all the British Islands are found freshwater lacustrine deposits in the upper parts of the marine Post-Pleiocene beds, showing the existence of ancient lakes that have been gradually filled up. In the marls and clays formed by these old lakes, which are very commonly covered by peat bogs, are often found the skeletons of animals, many of which are extinct, such as the great Irish elk.

In many caverns in the British Islands, under the floor of stalagmite that now spreads along their bottoms, has been found a deposit of mud or clay full of the bones of bears, hyænas, lions and tigers, elephants, etc. In some instances it is apparent that the caves have been used as the dens of the hyænas or bears, and the other animals' bones have been carried into them as prey.

Besides the "glacial drift" deposits, as those are called containing arctic shells and northern boulders, other drifted accumulations of a more or less local kind also occur in the shape of clay, sand, and gravel. These are sometimes found

to be older than the "glacial" deposits, but more frequently their relative date cannot be ascertained. Sometimes they are apparently of marine origin, but sometimes also fluvial, deposited by our present rivers when the land was at a slightly lower level, and the surface of the rivers consequently so much higher and often broader than at present.

There are fluvial and lacustrine formations which are not associated with any "drift," and are of a date clearly anterior to the "glacial" period. Round all the coasts of the British Islands and most other countries of the world are found "raised beaches,"—masses of sand, gravel, and shingle, with or without shells and other organic remains, just such as we see now on the present beaches, but at a height to which no possible tide could now attain. These are important rather as proofs of the elevation of the land than for their own sake, though in some places they are useful either for the lime of the shells or for other purposes. With these must be classed the "parallel roads" of Glenroy and other places, which are nothing more than old beaches marking the former margins of the sea when the land stood at a lower level.

The "submarine forests" on the contrary, which are so frequently found around the coast of the British Islands

and the north-west of Europe, prove the former greater elevation of the land than at present; thus rendering it necessary to suppose that the land has both risen and sunk, —risen at one part and sunk at another, and also risen altogether at one time and sunk at another.

We must class under this head, as belonging to the Post-Pleiocene period, such formations as the “loess” of the Rhine, and others, into the details of which we have no space to enter.

Finally, we have what are now known as “subaerial accumulations,” among which we must reckon all masses of fragments and detritus that have fallen from cliffs, and are now piled in heaps at their feet, all matters washed down by rain or by partial floods, as well as all blown sands and other similar things. These “subaerial accumulations” are probably of greater importance than has hitherto been supposed; some of them have been described by Mr. Austen.

It will perhaps be difficult to draw a very strong line between the Post-Pleiocene period and that which is called the Modern or might be called the Human period; and there are many disputed points still unsettled as to how far human bones have been naturally mingled with those

of extinct mammoths and mastodons and other animals now no longer seen living on the earth.

The Geologist however by no means ceases his labours when he arrives even at historic times. He has to trace and to describe the wasting away of cliffs and shores at some parts, the extension of lands at others, either by the piling action of the sea or by the growth of the deltas of rivers. He looks back to the time when for instance Lower Egypt was a bay of the Mediterranean, when the Gulf of Mexico extended far up into North America instead of receiving into its waters the long promontory which has been formed by the Mississippi, when the Ganges fell as a single stream into the Bay of Bengal some two hundred miles above the line of muddy coast where its divided waters now reach the sea.

Even in the wide ocean itself he finds great groups of coral-reefs and islands which are apparently even now in the process of formation; and by their study he arrives at a knowledge of great recent changes having taken place, and great accumulations of earthy matter having been formed, and being still forming, not only in the coral-reefs themselves, but in all the seas around, in consequence of their gradual erosion.

Mr. Darwin has shown that the groups of ring-formed coral-reefs called "Atolls," as also the "Barrier Reefs" encircling islands or bordering coasts with a deep sea-water channel between them and the land, are proofs of depression having taken place. In each case these reefs commenced as "fringing reefs," or masses of coral growing in the shallow water immediately bordering a coast; and as this land slowly sank down, the polyps continually grew and built upwards, in order to keep themselves within that limit of the surface, and its heat, light, and play of waves, that are essential to their existence.

If, as some geologists suppose, man was contemporaneous with many animals now long extinct, and of whose existence no tradition even has come down to us, and as some most eminent philologists contend, the least possible period we can assign to the duration of the human race upon the globe is one of 20, 30, or even 40,000 years, it may well be that some of these vast changes, these wide-spread deltas of mud and sand filling up great ocean gulfs, these huge piles of reef one or two thousand feet thick, slowly accumulated by the vital processes of the most feeble of animals, have yet all been produced within what may be strictly called the Modern or Human Period.

CHAPTER XVI.

ON THE AGE OF IGNEOUS ROCKS.

As the Aqueous rocks are capable of being arranged in a strictly chronological series, we are able by their means to acquire some knowledge of the age of any particular mass of Igneous rock. This is effected by studying the relations between the given igneous rock and the aqueous rocks around it.

If, for instance, we find any igneous cutting through, or sending veins into any aqueous rock, it is clear that the igneous is the newer of the two. If any aqueous rock has evidently been altered, hardened, or baked by the igneous rock, the same conclusion will be drawn. If, on the contrary, the aqueous rock contains any broken fragments or pebbles of the igneous rock, it is clear that the igneous is

the older rock of the two. Or, if the aqueous rock clearly conforms to the uneven surface of the igneous one, wrapping round its projections and filling up its hollows in such a way as to show they existed during its deposition, this latter conclusion holds good.

Finally, the igneous rock may be contemporaneous with the aqueous rocks in which it is found; that is, it may have been formed subsequently to the bed upon which it rests and before the bed that covers it: the latter point being ascertained either by the upper aqueous strictly conforming to the surface of the subjacent igneous, or by the igneous rock having altered the lower aqueous while it has not affected the upper one. In this latter case the age of the igneous rock is decided by the simple fact of superposition, which in the case of intrusive igneous rock is not any evidence of age. In the case of contemporaneous igneous rocks, it is very common to find their "ash" either just below, just above, or interstratified with them.

It is important to recollect that a contemporaneous igneous rock is always "intrusive" with respect to the bed on which it rests and all those below it; since, as all igneous rocks come from below, they must somewhere come up through all the previously formed beds, before they can

spread out upon the surface. The question whether any particular mass of igneous rock be contemporaneous with the group of beds in which it is found, or altogether intrusive and of subsequent origin, so that its age is absolutely uncertain, is one that in practice is often difficult to answer.

In determining the age of any mass of igneous rock, its mineral character taken by itself is of little or no assistance to us. Even in the case of granite itself, although we have some reason to suppose it probable that the earliest solidified rock upon the globe may have been a granite, still in the case of any particular mass of granite this is no guide as to its age, because we know that granite has been produced during all geological time, and believe it may be in course of production now, deep in the bowels of the earth. There are Primary Granites, Secondary Granites, and Tertiary Granites; the latter having been observed by Mr. Darwin in the Andes, where granite veins traverse Tertiary beds. The same may be said of all the other varieties of igneous rock.

It might at first sight appear as if we could mark out a few large periods of production in the igneous rocks, from their mineral character alone. For instance, we might say that there is no known scoriaceous lava or pumice in any

primary rocks ; or, generally, that the kind of rocks we call volcanic are never found among the older classes of rock, and the kind of rocks we call plutonic are never seen about any active or extinct volcanoes. It must however be recollected that we are here comparing things which are not properly comparable. In all the older formations we can find merely the deep-seated roots of any subaerial volcanoes that may have existed ; the whole surface of the ancient lands has long been destroyed, with all that was upon it. A well-preserved fossil volcano would be a rare accident, the result only of a combination of circumstances that perhaps would never combine. On the other hand, it is impossible for us now to thoroughly trace down any of our modern volcanic rocks to their deep-seated sources, and see whether they do or do not agree in their characters with the older igneous rocks. So far as we have been able to follow such investigations, the ascertained results increase the probability of the identity of igneous action in ancient and modern times. Any difference traceable between the igneous rocks of different geological periods depends on such minute points as these :—the older rocks are characterized by the presence of hornblende, the more modern ones by that of augite, (hornblende and augite being scarcely separable

minerals,) or one or two varieties of feldspar are more abundantly found in the ancient than in the modern rocks.

I will here give a few examples of the method of ascertaining the age of igneous rocks. The Wernerians always held granite to be a primitive aqueous rock; Hutton discovered in Glen Tilt granite veins traversing in every direction gneiss and mica-schist: this was a convincing proof of the granite being newer than the gneiss, and of its having been fluid when injected into the branching crevices of the gneiss. How much newer than the gneiss it is, there is no means of ascertaining.

The granite of Wicklow and the South-east of Ireland cuts through and alters the Lower Silurian rocks, but the Old Red Sandstone reposes on the granite in some places, undisturbed and unaltered, and moreover contains fragments of granite, and is itself composed of granitic detritus. This granite therefore is newer than the Lower Silurian (Cambrian of Sedgwick) and older than the Old Red Sandstone.

The granite of Cornwall and Devon cuts through the Culm measures, which are of carboniferous age; this granite therefore is newer than that of Wicklow, and more recent than the Old Red Sandstone, and than part, if not

the whole, of the Carboniferous period, but how much more recent we cannot exactly say.

North Wales abounds in examples of both contemporaneous and intrusive igneous rock, but they do not admit of succinct description.

The "toadstone" of Derbyshire, a kind of greenstone, is strictly contemporaneous with the mountain limestone in which it is found. This is shown, among other things, by the limestone strictly conforming to the upper uneven surface of the "toadstone," and even enveloping blocks and spheroidal masses of it, as I had an opportunity of seeing many years ago, in one of the mines there, and recorded in the 'Analyst.'

The "basalt" and "greenstone" of South Staffordshire are intrusive, and newer than the rocks immediately in contact with them, which are coal-measures: they are however probably not newer than the whole of the coal-measures there, as the upper beds contain sandstones made up of trappean detritus, and probably of the detritus of these very rocks.

The basalt and greenstone dykes figured in Plates XIV. and XV. are clearly newer than the Mountain Limestone of Ireland, but how much newer we have no evidence to tell us.

The basalt of the Giant's Causeway is evidently newer than the chalk on which it rests, which it alters, and which it cuts by dykes; it is therefore of Tertiary age. The Duke of Argyle has shown that the basalt of Mull and the neighbouring coasts is likewise of tertiary age, from the character of the fossils contained in some beds of "ash" interstratified with the basalt.

The great Cockfield Fell Dyke of the north-east of England runs for about sixty miles in a straight line, cutting through all the rocks from the coal-measures up to the oolites; it is therefore newer than the latter formation, but how much newer it is impossible to say.

These examples will perhaps be sufficient to give the reader an idea of the method of determining the age of any particular mass of igneous rock, and to show him the different kind of reasoning applicable to Igneous and Aqueous rock upon this point.

Part III.

CHAPTER XVII.

SKETCH OF THE GEOLOGICAL STRUCTURE OF THE
BRITISH ISLES.

IN order to understand the part devoted to this subject, it is essential that the reader should have before his eyes a geological map of the British Islands. The most convenient map for this purpose, is one published some years ago by Professor John Phillips. The excellent map by Professor Edward Forbes, in Johnston's Physical Atlas, is unfortunately divided into two, which diminishes its usefulness for our present service. A geological map of the British Isles has also been published by Mr. Knipe. For England alone Greenhough's map, the map by Sir R. Murchison in the Atlas of the Useful Knowledge Society, and for Ireland,

Griffith's map, or a smaller one lately published by Mr. M'Glashan, and called Frazer's Road-map, coloured geologically by Mr. Dunoyer, are the best authorities. For Scotland alone M'Culloch's is the only large map, though very inaccurate in its details. A smaller map will be found in Nicol's 'Guide to the Geology of Scotland.'

A broad band of metamorphic rocks, such as gneiss, mica-schist, and quartz rock, stretches in a direction nearly south-west and north-east, through the north-western portion of Ireland, and the whole of the north of Scotland, forming the Highlands of the latter country. Great masses of granite frequently protrude through this set of rocks in Galway, in Mayo, in Donegal, in Inverness, in Aberdeenshire, in Sutherlandshire, and in the Shetland Islands.

It is commonly believed that on the flanks of these granite masses the lowest or oldest rocks are to be found, having been lifted up on the protrusion of the granite. It may be doubted whether this is true in all cases, as the granite may have passed through the lowermost beds and have tilted up those above them.

The structure of any district composed of highly metamorphic rock is so difficult to make out, and requires such care and labour, that it is better perhaps to consider these

G. V. Du Roi, del.

KINDER SCOUT, DERBYSHIRE

Hillman & Walton Lith.

districts as yet unsurveyed, and not to enter any further on their details, but for the present remain content with the facts now briefly stated respecting them.

A Silurian (and Cambrian?) tract stretches from the county Cavan to the county Down on the north-east coast of Ireland, and thence across the southern part of Scotland, from Kirkcudbrightshire to the Lammermuir hills. Granite penetrates these Silurian rocks in the Mourne and Slieve Gullion mountains in Ireland, and in Criffel and in the Galloway hills, in Scotland. The general direction or strike of this district is likewise from south-west to north-east, or perhaps west-south-west to east-north-east, and in Scotland the general dip of the rocks is to the northward, or about north-north-west. What is their general dip in Ireland has never yet been stated, but in Scotland one is half-tempted to speculate as to whether these Silurian rocks of the Highlands of the Border, which have a thickness of at least 30,000 feet, and which dip from the south towards the north, under the Devonian and Carboniferous plain of the Lowlands, are not the same rocks which rise again in a metamorphosed condition from under that plain in the north, and form the lofty, broken and contorted country of the Highlands and the north of Scotland.

The Lake district of Cumberland and Westmoreland is a great, broken, dome-shaped mass of these rocks (Silurian and Cambrian), disturbed likewise by intrusive masses of granite and other igneous rocks, and dipping, roughly, in every direction from a central region, in which the lowest rocks are seen.

Further south again, we have the great Cambrian and Silurian district of Wales. This is a rudely semicircular or bastion-shaped mass, having a general strike of north-north-east and south-south-west, but slightly curving round, both on the north and the south, so that it acquires something of an east and west strike, and some large portions of it strike exactly east and west; still its lowermost beds are seen on the west, in St. David's Head, Carnarvonshire, and Anglesea, and its uppermost beds on the east, in Denbighshire, Montgomeryshire, and Shropshire, and in Hereford, Radnor, and Carmarthen. In North Wales a rudely dome-shaped mass of Cambrian rocks (of the Survey) rises between Barmouth and Ffestiniog, and another long anticlinal ridge behind Bangor and Caernarvon. Metamorphic rocks, such as mica-schist and gneiss, form the north-west side of the horn of Caernarvonshire, and spread widely over Anglesea. These are believed to be simply these same

Cambrian rocks, the Barmouth and Harlech group, in an altered condition. The Lower Silurians sweep round these Cambrian rocks, and are bent and contorted, together with all their contemporaneous and intrusive traps, into many and violent folds, the axes or anticlinal and synclinal lines of which run generally about north-east and south-west. These form all the highest mountains of North Wales, and, in consequence of their numerous great faults and cracks, and of the great subsequent denudation that has taken place about them, by which the rocks have been worn unequally into many broken valleys and ravines, produce the wild and beautiful scenery of that well-known country. As we proceed towards the east from Caernarvonshire, we find the rocks still undulating, higher and higher beds becoming dipped into the hollows of their folds, notwithstanding an occasional local protrusion of the lower rocks again, until they gradually sink into lower and broader undulations, and finally flatten into the more gentle features of Shropshire and Herefordshire.

On the opposite side of the Channel, Cambrian and Lower Silurian rocks occupy the whole south-east corner of Ireland from a little south of Dublin to a little east of Dungarvan. These have been broken through by a broad protrusion of

granite, stretching from Kingstown nearly to New Ross. At the northern end this granite appears to lift up to the surface, on one side of it, the lowest or Cambrian rocks, but not to bring them up on the other; while further south it seems to cut obliquely across the beds and to have the Lower Silurian rocks resting upon it, without the appearance of the Cambrian. The margin of the granite runs in a north-north-east direction, while the general strike of the stratified rocks is north-east. The Cambrian rocks rise again to the surface near Wexford, so that the general form of the Silurians of the south-east of Ireland seems to be that of a trough, with numerous included flexures, the axes, like those of Wales, running north-east and south-west. Little patches and protuberances of Silurian rocks are seen here and there along the east coast of Dublin and Meath, peeping from under the superior rocks, and serving to connect this south-east district with that before mentioned, on the north-east of Ireland.

The Silurians (and Cambrians?) of the Isle of Man, too, give us a connecting link between the Irish districts and that of Cumberland. Looking at it in this light, it appears probable that the basin of the Irish Sea is formed principally of these old rocks, and that the several Silurian dis-

tracts now described are really but separate portions of one large tract.

Disregarding the minor irregular protuberances and extensions of this large tract, we should find that there is a broad band of Lower Palæozoic Rocks, serving in great measure as a geological axis, running in a north-north-east direction from the mouth of St. George's Channel to the North Sea, which it enters by St. Abb's Head, in Scotland, separating the greater part of England on the east from the greater part of Ireland and Scotland on the west. The several parts of this extensive tract may be roughly described as—1. A uniclinal ridge, dipping north on the Scottish border, and extending probably into the north-east of Ireland. 2. A broken dome in Cumberland and Westmoreland. 3. A bastion-shaped mass in Wales. 4. A trough in the south-east of Ireland, broken on one side by a protruding ridge of granite.

In Ireland Silurian rocks again make their appearance further west, in the higher parts of some of the Tipperary and Clare hills, in Galway between Lough Mask and Killary Harbour, in the promontory of Dingle, and perhaps also in the mountains of Kerry and those on the borders of Kerry and Cork.

In all these latter cases they are found in isolated districts, which mark the sites of the local action of elevatory forces, which have thrust up the Silurian rocks within the reach of the denuding agencies that have subsequently worn off the upper rocks, and exposed the Silurians below. The Chair of Kildare is another still smaller district of the same kind.

The reader will recollect that the next set of rocks in the series above the Silurian is the Devonian. These rocks, in the well-known form of the Old Red Sandstone, rest upon the Upper Silurian rocks throughout South Wales and its borders, the two formations being in apparent conformity with each other. They occur, but in a very diminished form, through North Wales and northern England, where they appear as merely thin bands and patches. In the south of Scotland they are again found in considerable force on each flank of the high Silurian district of the border. On the north side of that lofty district they dip from it towards the north, and pass under the central plain of the Lowlands, from beneath which they rise again on to the flanks of the Highland mountains; here they form a broad continuous band, stretching right across Scotland, from the Clyde to Montrose and Stonehaven; they dip to the south, or from

the mountains, resting on the Metamorphic rocks quite unconformably, and enclosing fragments of them sometimes three or four feet in diameter. On the shores of the Murray Frith, and up the valley of the Caledonian Canal, the Old Red Sandstone is again largely developed, as also on the western coast, from Sleat Sound to Cape Wrath, its relations to the older rocks being the same as along the Highland border. The Orkney Islands are also principally composed of this formation.

In the North of Ireland the Old Red Sandstone occurs in a few large portions (as shown in Mr. Griffith's map) on the borders of the Metamorphic districts, but seems to die away towards the south, and to cease for awhile, or exist merely in shreds and patches, as it does in North Wales and the North of England, in about the same latitude. Still further south however it is found in considerable force, mantling round the hills of Clare, Tipperary, and the Queen's County, plunging in every direction from their central nuclei of Silurian rocks under the adjacent plains of carboniferous limestone. It peeps out also from under this limestone on the flanks of the granitic hills of Kilkenny, and spreads thence round the borders of the Silurian district of Waterford. Throughout all this district its lower beds are

greatly composed of conglomerate and breccia, the fragments of the Silurian rocks below ; and it rests on their upturned and contorted edges quite unconformably, sometimes in huge horizontal sheets, forming great mountainous masses, like the Commeraghs. From this point the Old Red Sandstone stretches to the Western Ocean, forming a great part of the wild hills and bold headlands between Cape Clear and Brandon Head. As it proceeds to the west however, from Kilkenny and Waterford, it puts on a new type, consisting more of slate than of sandstone,—grey, black, and blue slate above, and red and green and brown slate below. The whole formation is here thrown into a succession of long ridges and furrows, running about east-by-north and west-by-south, producing alternate long parallel elevations and depressions, ridges of bare, bleak, lofty ground rising towards the west into picturesque hills and mountains, and straight, nearly flat valleys, often of the richest and most beautiful character. These are features which all travellers must be familiar with in the south-west of Ireland.

This east and west strike of the rocks appears likewise in South Wales and the south-west of England. In Devon and Cornwall the slates, grits, and limestones, believed to be the representatives of the Old Red Sandstone, run east

and west, in a basin-shaped form, dipping on either hand from the coasts towards a central region occupied by a large mass of nearly unproductive coal-measures.

The history of the production of the Devonian rocks seems to be this:—At the close of the Silurian period, or during its later portion, great dislocations and elevations took place, by which the Silurian rocks, and especially the Lower Silurians of the larger and more northerly portions of the British Islands, became much broken and contorted, and in many places lifted up into dry land. Granite was protruded into them in the south-east of Ireland, and probably also the granites of the north-east of Ireland and of the north of England and south of Scotland, were formed at this time. Great denudation also took place, by which some of the granite of the south-east of Ireland (if not that of the other districts) was brought to the surface. Upon the uneven ground thus formed, as it was slowly depressed again, the Old Red Sandstone was deposited, consisting largely of the detritus produced by this denudation. But in the south-west of Ireland and England neither disturbance nor denudation took place to anything like the same amount, the locality remaining probably a pretty deep sea, in which fine-grained mechanical and some chemical

depositions were formed, partly contemporaneously with the Old Red Sandstone proper, and partly perhaps subsequent to it.

If we are allowed to continue this hypothetical history a little longer, we should say that at the close of the Devonian period a subsidence of almost the whole country had occurred, and in the sea thus formed was deposited the Carboniferous Limestone, resting in level sheets on the floor of Old Red Sandstone, that had filled up and levelled the hollows and inequalities in the older rocks. When the Carboniferous Limestone had been formed, the coal-measures were accumulated on the top of it, setting in first of all as thick sandy deposits, and then as alternations of sandy and shaly beds, with an occasional bed of coal. The depression being suspended, and the sea having been partially filled by the accumulation of the Carboniferous Limestone, was made still shoaler by the sandstones and shales of the Millstone Grit and Coal-measures, so that, according to some, it was entirely filled up to its surface, in order to produce a bed of coal, while every one agrees that it must have nearly been so. Depression then recommenced, allowing the accumulation of several thousand feet of Coal-measures, all successively produced in comparatively shoal water.

At the close of the Coal-measure period another period of partial elevation and disturbance took place in some parts of the district, while others remained sufficiently tranquil to allow of the deposition of the Permian Magnesian Limestone. After which, during the remainder of the Permian and the early part of the New Red Sandstone period, still further disturbance, elevation, contortion, dislocation, and enormous denudation, took place, giving to the rocks the features and relative position we are now going to describe.

CHAPTER XVIII.

STRUCTURE OF THE BRITISH ISLES (CONTINUED).

IN South Wales the Carboniferous rocks have assumed a rudely basin-shaped form, a rim of Carboniferous Limestone surrounding a long undulated trough of Coal-measures on all sides, except some parts of the south and west, where it is broken through by the sea.

The Forest of Dean coal-field is a smaller and more completely formed mass of the same kind,—a basin of Carboniferous Limestone containing concentric sheets of coal-measures. The Bristol coal-field is similar, but the basin is more broken and irregular, and its edges often overlapped and concealed by beds belonging to much newer formations.

Further north the Carboniferous Limestone seems to die out for a time, but thin strips of coal-measures resting on

the Old Red Sandstone and Silurian rocks run up through Gloucestershire and Worcestershire into Shropshire, where they are largely developed in the Coalbrook Dale coal-field. Coal-measures are found at intervals, resting on the older rocks, all across Shropshire into Flintshire, where the Carboniferous Limestone again sets in strongly, overlaid by the Millstone Grit, and that by the coal-measures. The formation thus composed strikes boldly through Flintshire to the sea-coast, the Mountain Limestone, unaccompanied by the superior rocks, bending over into the vale of Clwyd, which it borders all round, and then skirts the north shore of Wales to Great Orme's Head, the Menai Straits, and Anglesea, in the centre of which a small basin of coal-measures again comes in.

The carboniferous rocks thus make a semicircular sweep round Wales, from the sea of St. Bride's Bay to that of Caernarvon Bay.

If we proceed east from the Shropshire district, where the Silurian rocks project furthest into the plains of England, we find three outlying or isolated coal-districts, namely those of South Staffordshire, Warwickshire, and Leicestershire. The coal-measures of these rest directly on Silurian or Cambrian rocks, without the intervention of any Old

Red Sandstone or any Carboniferous Limestone, except a thin portion of the latter at the north end of the Leicestershire coal-field. We may imagine an old ridge of Silurian land to have still existed here during the Devonian and Carboniferous Limestone periods, preventing their deposition, but being gradually depressed afterwards, so that the coal-measures could be accumulated over it.

North of these, in Derbyshire and Staffordshire, rises a bold and lofty range of hills, which is continued thence to the Scottish border: they are known as the Pennine Chain. These consist of carboniferous rocks, lying in a broad anticlinal ridge, having the lower rocks in the centre, occupying the crown of the arch as it were, and the upper beds successively reclining one above another on either flank of it.

In Derbyshire the Carboniferous Limestone forms the central district, from the latitude of Ashbourne to that of Castletown, elevated in the centre into high land traversed by most picturesque dales, mostly with cliffy sides. The limestone beds decline on either side into a gentle valley composed of Limestone Shale, over which again rises an outer ring of hills formed of Millstone Grit, wild heathery moorlands, with craggy cliffs and rocky ridges at intervals. Plate XIX. gives a good idea of the features thus produced:

the spectator is standing among crags of Millstone Grit, south of Matlock, on the road to Wirksworth, the sweeping line of high ground on his right being composed of the same beds; below him is the valley of the Limestone Shale, which may likewise be traced into the distance; while on his left, over Matlock, rises the limestone hill of Masson Low, the beds of which incline gently to the right or eastward, and just before they pass under the Limestone shale are broken through by the Derwent, forming the High Tor, and the line of crags in the centre of the view.

In the north of Derbyshire and the borders of Yorkshire, the elevating and denuding forces not having acted so strongly, the Mountain Limestone is no longer exposed at the surface, being covered by the limestone shale and the millstone grit, which sweep right across the district in almost horizontal beds, forming some of the wildest moorlands of England, and traversed by the most secluded and scarcely accessible valleys. Of this scenery, Plate XX. will give an idea, being a view of part of Kinder Scout, one of the loftiest of these moorland tracts. On each side of the country thus described, as we fall into the lower levels, we come upon coal-measures, those on the east forming the Derby, Nottingham, and Yorkshire coal-field, those on the west the

Cheshire and Lancashire coal-fields. As we proceed to the north, these coal-fields increase in width, spreading further and further up towards the crown of the ridge, as if they also would shortly stretch right across it; when near Keighley, a little north of the latitude of Leeds, they are suddenly bent boldly back, and the lower beds rise out from below them to the surface, the Carboniferous Limestone spreading out on the Lancashire side, and the millstone grit on that of Yorkshire. The Carboniferous Limestone then sweeps round the mountains of Cumberland and Westmoreland, like a glacis round a citadel, and on the north side of them brings in the upper rocks and coal-measures, to form the Whitehaven coal-field. The central ridge is continued through Stanmoor Forest and the Weardale district, and the wild fells of Durham and Northumberland, up to the Cheviots. It is cut off abruptly by a great fault towards the west, bordering the Vale of Eden, but towards the east its beds decline gradually, to bring in the great Newcastle and Durham coal-field. As we proceed northwards we begin to lose the distinction of the several parts that we found in Derbyshire, and the whole carboniferous formation becomes one great series of coal-measures, with most interstratified limestones near the bottom, but with beds of coal throughout it. This is the case

with the Berwickshire coal-field on the south side of the Border mountains, and it is the case with the whole of the great Scotch coal-field, that occupies the district between the mouth of the Clyde and that of the Forth. This district has the general form of a trough, running nearly north-east and south-west, parallel to the other formations of Scotland, its beds reposing on the Old Red Sandstone, that rises out from under it on either side. On the north side its boundary appears pretty regular, but on the south much broken and convoluted, so as to form several small and isolated coal-fields, more or less completely surrounded by a margin of Old Red Sandstone. Igneous rocks, both contemporaneous and intrusive, are associated with the carboniferous rocks of the north of England, gradually increasing in quantity towards the north, and being most abundant in the Scotch coal-field, where they form some of the principal hills and most conspicuous features in the scenery.

If we proceed from Scotland into Ireland, we are first met by the little isolated coal-field of Ballycastle, on the north-east coast of Antrim, which reposes on and is bounded by mica-schist and other similar rocks; it probably belongs to the Scotch type of coal-measures, and is thus low down in the carboniferous series. Further south, in the counties

Tyrone, Fermanagh, and Sligo, we get a large district of carboniferous rocks, consisting of alternations of coal, shale, sandstone, and limestone, the coal principally in the upper portion, and the limestone in the lower; but it appears difficult at present to decide how far these Carboniferous rocks agree with the Scotch, rather than the English type. With many local contortions and disturbances, they appear to range on the whole in a nearly horizontal position through great part of these counties, having in their higher portions small isolated coal-fields, especially that of Dungannon and those of the county Leitrim.

In Roscommon the lower portion of the Carboniferous rocks, consisting almost entirely of limestone, spreads out with great persistency, and extends thence in wide, almost horizontal sheets, through the eastern half of the county Galway on the one hand, and through the centre of Ireland, consisting of the counties Longford, Westmeath, King's county, Kildare, Meath, and Dublin, on the other. So level is this great limestone plain, that the railroad across it from Dublin to Galway, without any deep cutting, or any tunnel from sea to sea, never traverses ground higher than 160 feet above the sea-level. Further south, the level sheets of the Carboniferous Limestone are tilted up,

and wrap round the Silurian and Devonian elevations of the Boughta and Inchiquin, and Slieve Bernah and Arra mountains in the county Clare, Slieve Phelim and Keeper mountains in Tipperary, and Slieve Bloom in the Queen's County. East of these the limestone stretches horizontally (disregarding local disturbances) through Kilkenny into the south of Tipperary, being covered by large masses of the Upper Carboniferous or coal-measure rocks, forming what may be called the Castlecomer and Balingarry coal-fields. West of them it spreads in the same way through the remainder of Clare into the counties of Limerick and Kerry and the north of Cork, being covered by a long district of coal-measures, stretching from Millstreet in the county Cork, across the mouth of the Shannon, nearly up to the south side of Galway Bay.

In the counties of Cork and Waterford and their borders the lower part of the carboniferous limestone becomes affected by the east and west lines of disturbance, which we before mentioned, as having bent and contorted the Devonian rocks of that neighbourhood. Several long narrow strips of limestone consequently are found in the long east and west valleys, having been folded into the hollows and troughs, and thus protected by their low level from the de-

nuding agency that has destroyed the rest of the carboniferous formation here. As we find thus in the south of Ireland carboniferous rock wherever the lower beds dip so as to render their occurrence possible with the present form and levels of the country, we are compelled to conclude that these rocks once extended over all the intermediate spaces, and that the carboniferous limestone, and most probably the coal-measures, once extended over nearly the whole of Ireland. The only probable islands of other rocks that once rose above the coal-measure plains* of Ireland, are the highest peaks of the five granitic districts of—1, Wicklow and Wexford; 2, Galway; 3, Mayo and Sligo; 4, County Down; 5, Donegal.

There is still one district of carboniferous rocks yet unmentioned—that of Devon and Cornwall. It has been reserved to this place, because in many things it resembles the South Irish rather than the English rocks. It consists of sandstones and shales, all more or less traversed by slaty cleavage and containing some beds of culm or anthracite. The coal-measures of the south of Ireland are likewise affected by slaty cleavage, and likewise contain culm or anthracite rather than bituminous coal. These culmiferous

* It is not intended to assert that these plains were then above water.

rocks of Devon and Cornwall occupy the centre of the east and west trough formed by the Devonian rocks. They have been pierced through, intruded on, and altered by the granite of Dartmoor, showing that the Devonshire and Cornwall granite is of more recent origin than that of the south-east of Ireland, which existed before the formation of the Devonian rocks.

CHAPTER XIX.

STRUCTURE OF THE BRITISH ISLES (CONTINUED).

Our descriptions have hitherto led us pretty equally into England, Scotland, and Ireland. For the future we shall be almost entirely confined to England. One is almost tempted to speculate on the great Silurian band of the Irish Sea and the south of Scotland, and which separates the mass of Ireland and Scotland from the mass of England, having been a permanent geological boundary from the Palæozoic times up to a recent Tertiary one. The Secondary and Tertiary formations found on the south-east side of it in England spread over a greater part of Europe, while only a few fragments and scraps of them are found on the north-west of it.

In England we find, round the hilly and mountainous

districts of Palæozoic rocks already described, level beds of New Red Sandstone, spreading from the foot of the hills into great plains, occupying a large part of the midland counties of Staffordshire, Worcestershire, Warwickshire, Leicestershire, and parts of Derby and Nottingham. These horizontal beds send one extension down the valley of the Severn to Bristol, and thence through Somerset and Devon to the mouth of the Teign; sweeping over the edges of the older rocks and running up their valleys, so as to level all their unevennesses up to a certain height. A similar extension runs through the county of York to the mouth of the Tces; but the beds here rest not on the upturned edges of older rocks, but on the almost equally level sheets of the last of the Palæozoic rocks, the undisturbed beds of the Magnesian Limestone and other Permian rocks. The third extension occupies the whole county of Cheshire, filling up the hollow between the hills of Wales and those of Derbyshire, as also part of the south and all the eastern coast of Lancashire, and the south-west coast of Cumberland. Similar flat beds run up the Vale of Clwyd in North Wales, and up the valley of the Solway Frith and its borders, both into Scotland on the north and up the Vale of Eden on the south. These same beds too, equally in a nearly horizontal

position, are found in the county Antrim and its borders, appearing from under other superincumbent matters in such a way as to make it probable that its concealed portion spreads nearly over the whole county.

In this direction therefore there appears a break or gap in our supposed Silurian boundary. We might imagine it a large strait or bay, occupied by the New Red Sandstone sea, and surrounded by a land of Palæozoic rocks.

The structure of the rest of England is very simple. The Secondary rocks, from the Lias to the Chalk inclusive, strike regularly across it in a north-north-east and south-south-west direction from the English Channel to the German Ocean, all their beds dipping gently to the east-south-east. The softer and more easily worn portions of these formations make plains or valleys, the harder and stronger portions long ridges of hills, having a steep face or escarpment to the west, where their beds end abruptly, and a gentle slope to the east, in which direction they pass gradually into the ground under the superior beds. We have thus the plain or valley of the Lias, running from Lyme Regis in Dorsetshire to a little south of the Tees near Whitby in Yorkshire. Over this comes the Oolitic escarpment, making a ridge of high ground, of which the Cotswolds in Gloucestershire

and the Yorkshire moorlands are the most conspicuous parts, running from Bridport to the neighbourhood of Whitby. Then across the greater part of England comes a plain composed of the Oxford and Kimmeridge Clays, with isolated ridges of Coral Rag, and the gently undulating ground of the Lower Cretaceous rocks, bounded on the east by a bold ridge of Chalk; forming a long range of high ground parallel to the Oolitic escarpment. At two places however, namely in Dorsetshire and in the south-east of Yorkshire, the Chalk overlaps the beds below, so as to rest directly on the Lower Oolites. In the Yorkshire Wolds indeed the Oolitic escarpment disappears altogether, being buried under the Chalk.

As the Chalk dips gently to the east, it becomes buried more and more by the Tertiary rocks, the Plastic Clay, the London Clay, and the Crag, previously described. These stretch from the north-east coast of Norfolk, down into Hampshire, with one remarkable interruption, but for which it would appear as if the whole of the south-eastern counties of England, between the two just named, and including Kent and Sussex, would have been a level plain of soft and incoherent Tertiary rocks. This interruption is a broad ridge of Chalk, that stretches from Salisbury Plain to the

country north-east of Winchester, near which it divides into two ridges,—one, the North Downs running through Kent to Dover; the other, the South Downs, through Sussex to Beachy Head. The beds of these North and South Downs dip north and south respectively, exposing the inferior rocks, namely the Lower Cretaceous and the Wealden, in the valley between them. In the centre of this valley rises another isolated ridge, formed of the Hastings Sand, arching over the anticlinal axis, which runs nearly east and west, from about Winchelsea to near Salisbury Plain. The beds, having been bent into an arch over this line, have been largely removed by denudation, the denudation being greater and greater as we proceed from west to east: first, the Tertiaries have been washed away from off the surface of the Chalk about Winchester; then the Chalk removed from the Upper Greensand about Woolmer Forest; then the Upper Greensand from the Lower Greensand, and that from the Weald Clay, till we come down to the Hastings Sand, which has not been entirely denuded. This valley of Kent and Sussex, called the Weald, is a beautiful instance of a valley of denudation. It shows also how the several formations are continued in great sheets one under the other, and are found re-appearing at the surface in regular order,

in any spot from which the upper beds may chance to have been removed. In consequence of this sudden elevation of the inferior rocks, the Tertiary formations of the south-east of England are separated into two parts, occupying two rudely basin-shaped depressions, called respectively the London and Hampshire Basins. Further south, in the Isle of Wight, and what is called the Isle of Purbeck, the Chalk and other lower rocks are again suddenly and violently upturned along a line running due east and west, the beds in some parts being absolutely vertical. We thus get the east and west strike remarked before in the rocks of Devon and Cornwall and the south-west of Ireland, and which was the result of disturbances acting before the New Red Sandstone was deposited, repeated in the south-east of England at a period more recent than the Eocene, but how much more recent we cannot say. In the north-east of Ireland we have, above the New Red Sandstone mentioned before, Lias and Greensand and Chalk, but very imperfectly developed, never exceeding ten to thirty feet for each formation. Over the Chalk is a vast plateau of Basalt, apparently of the same age as that of the Isles of Skye and Mull and Staffa in Scotland. This basalt, as shown by the discoveries of the Duke of Argyle, is of true Tertiary origin. It

covers Lias and other Oolitic rocks in Scotland, in which country there are also some strips of Oolitic rocks plastered on the north shore of the Murray Frith.

Of the spread and distribution of the superficial deposits of Post-pleiocene age, the "glacial" and other drift deposits, we shall not attempt to give any account. No general maps of them have yet been attempted, and any account of them would lead us into a great quantity of details foreign to the character of this very general and rapid sketch.

CHAPTER XX.

CONCLUSION.

THERE are two subjects on which I would wish to say a few words in conclusion, because, having been often questioned respecting them, it seems that many people are anxious for further information on them. The first subject is a theoretical one, namely, the antiquity of the earth; the other practical, namely, what is the precise utility of geological investigation.

The Antiquity of the Earth.—The time is almost entirely gone by when Geologists were assailed by well-intentioned but unreasoning obloquy on this point. Most people are now content to take the authority of Geologists as to the age of the globe, on the same footing as they do that of Astronomers as to the relative size, distance, and motions of the

heavenly bodies. They wish however, in the one case as in the other, to have the nature of the proof popularly explained to them. I will therefore here endeavour to sum up the geological evidence in proof of the vast, the almost inconceivable antiquity of the globe on which we live.

This subject was entered on in Chapter XIX., but though the nature of the evidence was there spoken of, and the kind of proof pointed at, the actual conclusions were not drawn, nor indeed could they have been properly arrived at, till the stratigraphical series had been described, and an example given of the extent of the several formations, and the way in which they enter into the structure of a large district.

I must first of all allude to the palæontological evidence, in order to show how it combines with and corroborates that drawn from physical structure.

The reader will recollect that not only every system and formation, but in many cases every group and even every set or stage of beds, was spoken of as characterized by particular assemblages of fossil animals or plants. In other words, there have been a succession of races of animals and plants inhabiting the globe, the species of which (and in many cases even the genus and family) have come into exis-

tence, have spread and multiplied, and then have gradually died out and become extinct, and been succeeded by others. It is true that in every case those animals and plants, the remains of which have been preserved for our inspection, formed probably but an insignificant part of the whole assemblage of animals and plants which were their contemporaries; but this strengthens rather than weakens our argument, because the longer any species lived upon the globe, the greater was its chance of meeting with such a set of circumstances as should cause its remains to be preserved. The fossil animals and plants now known to us, therefore, were, *cæteris paribus* and in the majority of instances, those whose time of existence on the globe was the *most* protracted, rather than the contrary. It is true also that our conclusions are mainly drawn from one sort of animal remains—those of the Mollusca, namely, that had shells and lived in the water; but here again, wherever we can find the remains of other sorts of animals—fishes, reptiles, birds, or mammalia—the evidence derived from their examination goes in the same direction, and commonly even *further in that direction*, than that derived from the examination of Mollusca. In other words, it appears that Molluscan animals are those that are most long-lived and enduring as far as regards the

continuance of the species ; or that a space of time necessary for bringing about a certain change in the species of *shells* would be marked by a still greater change in the species of other animals, and especially in those of a higher order.

Now, even if, for the sake of argument, we limit the existence of man on the globe to a space of 6000 years, we find that the change in the races of animals and plants that has taken place in that interval is so small and insignificant, as to raise our estimate of the time that will be required for the extinction of any large proportion of those now existing, to an enormous amount. But as we must found our reasoning solely on facts that have been observed and recorded, and can only argue as to past time on the same premises that we use with respect to present and future, we are compelled to allow a still more enormous amount of time for the production of those many entire changes in the assemblages of species of animals and plants which we meet with in palæontological investigation.

Palæontology therefore forces us either to have recourse to the fantastic notion of the creation of forms which could have no other object or end than that of puzzling, leading astray, and deceiving the faculties of the human mind, or to

admit that the earth has existed pretty much as we now see it, and inhabited by animals and plants living in an exactly similar way to our own contemporaries, through a lapse of past time so vast, that, compared with our own finite faculties and our petty lives, it may well be likened to eternity.

If now, dismissing the palæontological part of the subject, we look simply to the physical structure of the crust of the earth, we get the following evidence of lapse of time.

If the reader took the trouble to add together the maximum thicknesses of the several formations spoken of in Part II., he would find it amount to a total of about 94,000 feet, or more than seventeen miles*. Now some parts of this vast quantity of sedimentary rock were doubtless ac-

* I must again caution the reader against concluding it necessary to suppose, even for a moment, that there is in any *one part* of the earth's crust this thickness of sedimentary rock, or even the half or the quarter of it. All that is necessary for our argument, is to suppose that the different masses of sediment, formed *successively*, now in one place, now in another, would, if their thickest portions were taken and placed one upon another, amount to seventeen miles. If a thousand feet of rock be deposited at A during a period when none at all was thrown down at B, and if after the close of that period another thousand was accumulated at B, while none at all was deposited at A, it is plain that we must take 2000 feet of sediment as the measure of the whole time elapsed, even if we cannot find any third place, C, where the whole 2000 feet are all present together.

cumulated with great rapidity, but other parts with the utmost slowness: whatever mean rate of deposition however we may allow, it is clear that, for any kind of aqueous action to have deposited this amount of sediment, a space of time must have elapsed, compared with which such a term as 6000 years is utterly insignificant. This would be the case even if we allowed of no pause or cessation in this action of deposition, but supposed the 94,000 feet to have been the result of one uninterrupted stream of aggregation of earthy matter. So far however from this being the case, it appears far more reasonable, and often absolutely necessary, to conclude that the time occupied by the actual deposition or formation of the several portions of this series of sedimentary rock, was but a very small part of the whole time that intervened between the formation of the oldest bed and the present day. The whole series of strata is made up of separate beds, which on an average perhaps are not more than a foot or two in thickness. For all we know to the contrary, the interval that elapsed between the formation of any two successive beds, may have been far greater than that which sufficed for the production of either of them. If we come to examine the laminæ of deposition of different beds, we find

that we have in them the evidence of a succession of deposits that were probably often of a periodical character. In shales and shaly sandstones each thin paper-like layer may mark an annual deposit, the result of a periodical flooding of some great adjacent river or other similar action. A bed of shale a foot thick may often then have required a century for its production; the interval that elapsed between the production of one bed and that of the next above it may have been equal to one or many centuries. If we calculated the time requisite for the production of the whole of the beds of any formation, and then doubled it for the time elapsed in the intervals between the beds, we should probably under-estimate the whole time.

Moreover, as individual beds are very seldom continuous over very large areas, we are apt, in examining any set of beds, to assume a synchronism that probably did not really exist. The set of beds may preserve a mean thickness of 100 or 500 feet throughout, and yet may be made up of an assemblage of comparatively small cakes of matter, hardly one of which was deposited exactly at the same time with another. So that if we placed them all one upon another in the order of their times of production, the 100 or 500 would swell out to some thousands of feet. We are apt to

look on the act of deposition as the rule, and the pauses as the exceptions; whereas, in all probability, the very reverse was the fact in any given area, sedimentary matter being really deposited at wide intervals during a general period of repose. But if this allowance for repose be necessary for the intervals between beds that at first sight seem almost immediately consecutive, what shall we say for the intervals between the several sets or stages of beds,—for those between the different groups,—and lastly for those between the different formations and systems? We are driven here wholly to conjecture; we have no measure or guide whatever. If, on the one hand, we choose to suppose that the intervals were relatively small, we have, on the other hand, no good ground for denying them to have been almost infinitely great compared with the times employed in production. Moreover the further we push our investigations and researches, the more do we become inclined to believe in the magnitude of past time, and the very slow and gradual step-by-step and interrupted process of the production of the aqueous rocks. We must recollect that the sedimentary rocks are the result largely of erosion. Before the sediment can have been deposited in one place it must have been worn off previously-existing rock in another, and carried

for an unknown distance between the two. Moreover the instances are comparatively rare in which the erosive action has taken place directly on an originally-formed rock, and the resulting detritus gone immediately to form one of our existing rocks. In the majority of instances the materials of our present clays, sands, shales, sandstones, etc., have formed part of other sedimentary rocks, perhaps of one, perhaps even of many successively, before they were deposited in that rock where we now find them.

This brings in another element into our calculation:—not only is the stratigraphical series not the result of continuous, but of interrupted deposition,—not only were there intervals when nothing was being deposited in the places from which our data are taken, but there were other intervals during which rocks that had been previously deposited were being destroyed. Vast masses of rock, that marked the lapse of immense periods of time (required for their deposition), have been entirely destroyed, and sometimes perhaps so utterly removed that we have not yet discovered the portions that were left. In all probability the average time required for the erosive destruction and removal of any mass of sedimentary rock, is as great as what was required for its formation, if not greater. We come then to

look on our stratigraphical series as but a series of relics of the whole amount of the work of production that has been effected during past geological time; and however great may be our estimate of the time necessary for the production of the portions that have been preserved to us, even that sinks into insignificance compared with the whole amount of time marked by the absence of sedimentary production, or by the destruction of that which had been produced.

These conclusions are strengthened and confirmed when we come to consider the evidence we have of the same portion of the earth's surface having been several times covered by a deep sea, and converted into dry land,—of its having at one time been a solitary islet, at another part of a great continent traversed by large rivers and containing great fresh-water lakes. Judging by the rate of change now going on upon the earth's surface—our only safe standard of measurement—how vast must have been the periods required for these changes!

If, again, we look to the rocks derived from igneous action, we find the clearest evidence of one and the same area having been at one time ravaged and convulsed by subterraneous fires,—of the commencement of this action

of its having gradually increased and extended, and then of its having as gradually ceased and died away; and this, not once only, but several times within the same area of the earth's surface. How small comparatively has been the change in our present volcanoes, during the hundreds of years they have been known to us! How vast appears to us the lapse of time necessary for *Ætna*, for instance, to become extinct, to be gradually depressed below the sea, and to be as gradually eroded and worn away by the breakers, until the whole mountain is planed smoothly off, and nothing but its submarine roots left entangled with the beds which were contemporaneous with its commencement! Yet this process, or something very similar to it, has occurred more than once even within the area of the British Islands.

Again, if we look at the vast disturbances, the great cracks, faults, and contortions that are found in any area, we are driven either to the unnecessary and unfounded hypothesis of former great and sudden convulsions, or to suppose immense periods of time necessary for their production; and many of these periods of time, alternating with periods of repose, can be shown to have occurred in every considerable area of the earth's surface that has hitherto been examined.

The reader will now see that the argument for the immense and utterly unknown and unimaginable antiquity of the earth is a cumulative one of the strongest possible kind. Into whatever branch or department of Geological science we extend our researches, we meet with many individual proofs of the lapse of long periods of time. Each of these individual proofs is in itself conclusive on this point, and is backed up and corroborated by others of like nature belonging to its own department. Similarly all the several departments combine together, not only to corroborate the proof, but to extend and enlarge the periods of time that must necessarily be admitted to have elapsed, unless we are content at once to abandon all reasoning on the matter, to shut up the use of our faculties, and to debar ourselves from their exercise on one of the most sublime and most elevating subjects on which they can be employed.

The Practical Utility of Geological Investigation.—On this point, strange as it may seem, there is among the general Public a greater amount of scepticism and mistrust than in the one which has been just treated of. It may perhaps seem still more strange for a Geologist to assert that there has been hitherto greater reason for this mistrust on the practical than on the theoretical point; yet such I believe to be

the truth. The scientific Geologist, eager in the search after his own grand generalizations, has hitherto hardly deigned to afford that amount of practical assistance to the arts and uses of life which the science is capable of rendering. The science of Geology must be practised as a profession, must become the means of subsistence and the road to *wealth*, as well as *distinction*, before it can give all the use it is capable of, to Society. It is alike idle and absurd to lament this necessity,—it is a law of our nature. Advice on practical matters, when given gratuitously, is acted on solely at the risk and on the responsibility of *him that takes it*; when afforded professionally and paid for, it is both more carefully and scrupulously given, and is put into practice on the responsibility of *him that gives it*. If it be bad, the giver suffers in his professional prospects at all events, if in no other way. Sound geological advice and opinion on practical points, therefore, will only begin to have a general existence when a body of professional geologists shall have been some time in existence. Viewed in this light, the general mistrust of geologists among practical men is warranted.

There is however another perfectly unwarranted and ignorant reason, both for the general mistrust of, and for occasional instances of blind confidence in, the practical

value of geological investigation, and this is a total misconception of the methods of geological research. People often fancy that the Geologist either does or ought to possess some mysterious faculty of piercing with his mind's eye deep into the bowels of the earth, and of telling at once, from a glance at the surface of any particular spot, the nature and position of the materials below it. Take a Geologist to any district he has never seen before, of which he has never heard or read a description, never seen a map, and which is quite removed and at a distance from any place he does know, and he would, ten to one, be able to say or to know just as little about what lay below the surface as any other man. The only difference between him and another person would be, that he would at once know how to set about obtaining the requisite information. Practical geology is entirely *experience*: almost every farmer, every brick-maker, every stone-mason, quarryman, collier, and miner is a practical geologist *so far as his experience goes*. Within that limit each of those classes of men are commonly better practical geologists than the most scientific and learned of the race. The difference between them and the real geologist is that his experience is greatly wider and more varied than theirs.

The value of a really scientific and practical Geologist is, that he has been able to correct the errors that naturally arise from local and partial observation,—that he is acquainted with the real nature and the method of the production of the things with which he has to deal,—and that, besides the probabilities, he is acquainted with the possibilities of any particular case (after adequate investigation), and that he will be able to give an authoritative and trustworthy opinion both as to what probably will be found, and as to what *certainly will not* be found in any particular locality.

The utility of detailed and minute geological investigation must obviously be great as to all operations depending on or connected with anything below the surface of the ground. Agriculture, clay-digging, quarrying, road-making, cutting and tunnelling, mining operations of every kind, can all be aided by the Geologist, and the aid is directly proportionate, for the most part, to the minuteness of his investigations and the large scale of the maps on which he is able to record and harmonize his observations.

The scale of the maps (supposing them to be accurate) on which a Geologist works, is an element so very important in estimating the practical utility of his work, that,

cæteris paribus, it depends almost solely on that single point.

In England, as long as the old county maps only existed, the best geological work could only be vague and imperfect; when the inch map of the Ordnance Survey came into existence it became possible to do geological work of a much more accurate and much more detailed and practical character than before; on the six-inch map of the Ordnance Survey of Ireland and parts of the north of England, it is possible to adopt a system of geological work of a very high order of exactness and practical utility. In every case it is almost essential that the map be a general one of the whole country. The most practised geologist, if he examined merely a small district—as for instance one person's property—would be liable either to fall into errors or to meet with difficulties and obscurities, for the clearing up of which he would have to examine large neighbouring districts, and in some instances even very distant localities*.

* At the risk of being taunted with the old proverb that “There is nothing like leather,” I will point out here the value and necessity of a national or Government Geological Survey, the results of which shall be accessible to the public at large. I could give instances, within my own experience on the Geological Survey of the United Kingdom, of most important light being thrown on one district by the examination of another at a considerable dis-

Geological knowledge, like every other kind that is worth having, is of slow growth and can only be acquired by hard labour. Any one who chooses, in commencing any practical operation below the surface of the ground, to rely on his own judgment and experience, must run the risk of finding that he has not worked hard enough to acquire a sufficient stock of those valuable articles; and to find, to his cost, that had he purchased the advice of those who had, he might have saved money in the end. This conviction will gradually gain strength and extension in the public mind, until a set of practical geologists gradually come to rely on it for their subsistence in life. A certain degree of unskilfulness and incapacity may characterize this class of men at first, but it will gradually disappear with more extended experience, and they will ultimately acquire, and become worthy of, the confidence of the public. When that time arrives, no prudent man will even venture to open a gravel-pit or a clay-pit, or to dig a foundation for his house, or to lay out the

tance from it,—of points having a directly and most valuable practical bearing, being only obscurely indicated in one district, the interpretation and meaning of those indications being clearly shown in another, where they were observed by my colleagues, and the information thus gained brought to bear on my own work, which would have been, and must have remained, imperfect without it.

drains on his land, or even perhaps to select the manure for his farm, without first paying for geological advice. In the majority of instances he will find his advantage in it. Even at the present day the opinion is gaining ground among all mining men, that no mining operations should be tried on unexplored ground without geological advice. I have elsewhere remarked*, that even within the last twenty years I have known, within my own experience, as much money expended or thrown away in abortive searches after coal, in places where geologists could at once have declared the impossibility of finding it, as would have paid the cost of the entire Geological Survey of the United Kingdom.

* Records of the School of Mines, vol. i. part 2.

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