mountain sides have been washed bare of their soil. The desiccation of the countries bordering the eastern Mediterranean has been ascribed to a similar cause. 5. In mountain districts pine forests exercise also an important conservative function in preventing the formation or arresting the progress of avalanches. In Switzerland some of the forests which cross the lines of frequent snow-falls are carefully preserved.

Animals do not exert any important conservative action upon the earth's surface, save in so far as they form new deposits, as will be immediately referred to. In the prairie regions of Wyoming and other tracts of North America, some interesting minor effects are referable to the herds of roving animals which migrate over these territories. Professor Comstock describes the trails made by the bison, the elk, and the big-horn or mountain-sheep as firmly-trodden tracks on which vegetation will not grow for many years. All over the region traversed by the bison numerous circular patches of grass are to be seen which have been formed on the hollows where this animal has wallowed. Originally they are shallow depressions formed in great numbers where a herd of bisons has rested for a time. On the advent of the rains they become pools of water; thereafter grasses spring up luxuriantly, and so bind the soil together that these grassy patches, or "bison-wallows," may actually become slightly raised above the general level if the surrounding ground becomes parched and degraded by the winds (*Reconnaissance of N.W. Wyoming*, 1875, p. 175).

III. Reproductive Action.—Both plants and animals contribute materials towards new geological formations. Their remains are enclosed in deposits of sand and mud and there preserved. But they form of themselves not unimportant accumulations. Of plant formations the following illustrative examples may be given. (1.) *Peat-Mosses.*—These are accumulations of marshy vegetation which occur in temperate and arctic latitudes, sometimes to a depth of 40 feet or more. In Europe they have been largely formed by plants of the genus *Sphagnum*, which, growing as a spongy fibrous mass over wet ground, die in their lower parts and send out new fibres above. It is this lower decaying stratum which forms the peat. Every stage of the process may be seen in a large moss, from the green living plants at the top, through fibrous brown turf full of the scarcely decayed rootlets of the *Sphagnum*, down to the compact brown or almost black peat at the bottom. Many peat-mosses were at one time lakes which have been gradually filled up by the accumulation of marsh-plants. Peat possesses a great antiseptic power; the bodies of animals which have been entombed in it are sometimes preserved for many centuries. (2.) *Mangrove Swamps.*—On the low moist shores and river mouths of tropical countries, the mangrove tree plays an important geological part. It grows in such situations in a dense jungle, sometimes 20 miles broad, which fringes the coast as a green selvage, and runs up if it does not quite occupy creeks and inlets. The mangrove flourishes in sea-water even down to low-water mark, forming there a dense thicket which, as the trees drop their radicles and take root, grows outward into the sea. It is singular to find terrestrial birds nestling in the branches above and crabs and barnacles living among the roots below. By this network of subaqueous radicles and roots the water is filtered of its sediment, which, retained among the vegetation, helps to turn the spongy jungle into a firm soil. On the coast of Florida the mangrove swamps stretch for long distances as a belt from 5 to 20 miles broad, which winds round the creeks and inlets. At Bermuda the mangroves co-operate with grasses and other plants to choke up the creeks and brackish lakes. In these waters calcareous algæ abound, and as their remains are thrown up amidst the sand and vegetation they form a remarkably calcareous soil. (3.) *Diatom Mud or Earth.*—As the minute siliceous plants called diatoms occur both in fresh and salt water, the deposit formed from their congregated remains is found both on the sites of lakes and on the sea-floor. "Infusorial" earth and "tripoli powder" consist mainly of the frustules and fragmentary debris of diatoms which have accumulated on the bottoms of lacustrine areas. Towards the Antarctic circle the "Challenger" met with *Diatomaceæ* in abundance, both in the surface waters of the ocean and on the bottom. They form at depths of from 1260 to 1975 fathoms a pale straw-coloured deposit, which when dried is white and very light.

Animal formations are chiefly composed of the remains of the lower grades of the animal kingdom, especially of *Mollusca*, *Actinozoa*, and *Foraminifera*. (1.) In some cases they are *calcareous*. Lime, chiefly in the form of carbonate, is the mineral substance of which the solid parts of animals are mainly built up. Hence the great majority of the accumulations formed of animal remains are calcareous. In fresh water they are represented by the *marl* of lakes—a white, chalky deposit consisting of the mouldering remains of *Mollusca*, *Entomostraca*, and partly of fresh-water algæ. On the sea-bottom in shallow water they consist of beds of shells, such as the oyster-banks of English seas. The fringing, barrier, and atoll coral-reefs of warm seas are conspicuous examples of wide and thick masses of rock formed from the accumulated growth of animal organisms. The great reef of Australia, for example, is 1250 miles long, from 10 to 90 miles broad, and more than 1800 feet thick. The coral rock, though formed by the continuous growth of the polyps, gradually loses any distinct organic structure, and acquires an internal crystalline character owing to the infiltration of water through its mass, whereby carbonate of lime is carried down and deposited in the pores and crevices as in a growing stalactite. Great quantities of calcareous mud are produced by the breakers which beat upon the outer edge of the reefs. This mud is partly washed up upon the reefs and aids in their consolidation, but in great measure it is swept away by the ocean currents and distributed over many thousands of square miles of the sea-floor. In deep water over the bed of the Atlantic and other oceans a remarkable calcareous ooze occurs which is formed of the remains of *Foraminifera*, and chiefly of species of the genus *Globigerina*. It is next in abundance to the red and grey clays of the deep sea. It is a pale-grey marl, sometimes red from peroxide of iron, or brown from peroxide of manganese; and it usually contains more or less clay, even with occasional fragments of pumice. (2.) *Siliceous* deposits formed from animal exuviæ are illustrated by another of the deep-sea formations brought to light by the "Challenger" researches. In certain regions of the western and middle Pacific Ocean, the bottom was found to be covered with an ooze consisting almost entirely of *Radiolaria*. These minute organisms occur, indeed, more or less abundantly in almost all deep oceanic deposits. From the deepest sounding yet taken (4575 fathoms, or more than 5 miles) a radiolarian ooze was obtained. The spicules of sponges likewise furnish materials towards these siliceous accumulations. (3.) *Phosphatic* deposits, in the great majority of cases, betoken some of the vertebrate animals, seeing that phosphate of lime enters largely into the composition of their bones and occurs in their excrement. The most typical modern accumulations of this nature are the guano beds of rainless islands off the western coasts of South America and Southern Africa. In these regions immense flocks of sea-fowl have in the course of centuries covered the ground with an accumulation of their droppings to a depth of sometimes 30 to 80 feet, or even more. This deposit, consisting chiefly of organic matter and ammoniacal salts, with about 20 per cent. of phosphate of lime, has acquired a high value as a manure, and is being rapidly cleared off. It could only have been

preserved in a rainless or almost rainless climate. On the west of Europe isolated stacks and rocky islands in the sea are often seen to be white from the droppings of clouds of sea birds; but it is merely a thin crust, which is not allowed to grow thicker in a climate where rains are frequent and heavy.

IV. Man as a Geological Agent.—No survey of the geological workings of plant and animal life upon the surface of the globe can be complete which does not take account of the influence of man—an influence of enormous and increasing consequence in physical geography, for man has introduced, as it were, an element of antagonism to nature. Not content with gathering the fruits and capturing the animals which she has offered for his sustenance, he has, with advancing civilization, engaged in a contest to subdue the earth and possess it. His warfare indeed has often been a blind one, successful for the moment, but leading to sure and sad disaster. He has, for instance, stripped off the woodland from many a region of hill and mountain, gaining his immediate object in the possession of their stores of timber, but thereby laying bare the slopes to parching droughts or fierce rains. Countries once rich in beauty, and plenteous in all that was needful for his support, are now burnt and barren, or washed bare of their soil. It is only in comparatively recent years that he has learnt the truth of the aphorism—"*Homo Naturæ minister et interprés.*"

But now, when that truth is coming more and more to be recognized and acted on, man's influence is none the less marked. His object still is to subdue the earth, and he attains it, not by setting nature and her laws at defiance, but by enlisting her in his service. Within the compass of this article it is impossible to give more than merely a reference to this vast subject. The action of man may be witnessed on climate, on the flow of water, on the character of the terrestrial surface, and on the distribution of life.[1]

1. *On Climate.*—Human interference affects meteorological conditions—(1) by removing forests and laying bare to the sun and winds areas which were previously kept cool and damp under trees, or which, lying on the lee side, were protected from tempests; as already stated, it is supposed that the wholesale destruction of the woodlands formerly existing in countries bordering the Mediterranean has been in part the cause of the present desiccation of these districts; (2) by drainage, the effect of this operation being to remove rapidly the discharged rainfall, to lessen the evaporation, and thereby to diminish the rainfall and somewhat increase the general temperature of a country; (3) by the other processes of agriculture, such as the transformation of moor and bog into cultivated land, and the clothing of bare hillsides with green crops or plantations of coniferous and hardwood trees.

2. *On the Flow of Water.*—1. By increasing or diminishing the rainfall man directly affects the course of the waters over the land. 2. By his drainage operations he makes the rain to run off more rapidly than before, and thereby increases the floods in the rivers. 3. By wells, bores, mines, or other subterranean works he interferes with the underground waters and consequently with the discharge of springs. 4. By embanking rivers he confines them to narrow channels, sometimes increasing their scour, and enabling them to carry their sediment further seaward, sometimes causing them to deposit it over the plains and raise their level.

3. *On the Surface of the Land.*—Man's operations alter the aspect of a country in many ways:—(1) by changing forest into bare mountain, or clothing bare mountains with forest; (2) by promoting the growth or causing the removal of peat-mosses; (3) by heedlessly uncovering sand-dunes, and thereby setting in motion a process of destruction which may convert hundreds of acres of fertile land into waste sand, or by prudently planting the dunes with sand-loving vegetation or pines, and thus arresting their landward progress; (4) by so guiding the course of rivers as to make them aid him in reclaiming waste land, and bringing it under cultivation; (5) by piers and bulwarks, whereby the ravages of the sea are stayed, or by the thoughtless removal from the beach of stones which the waves had themselves thrown up, and which would have served for a time to protect the land; (6) by forming new deposits either designedly or incidentally. The roads, bridges, canals, railways, tunnels, villages, and towns with which man has covered the surface of the land will in many cases form a permanent record of his presence. Under his hand the whole surface of civilized countries is very slowly covered by a stratum, either formed wholly by him, or due in great measure to his operations, and containing many relics of his presence. The soil of old cities has been increased to a depth of many feet by the rubbish of his buildings; the level of the streets of modern Rome stands high above that of the pavements of the Cæsars, and that again above the roadways of the early republic. Over cultivated fields his potsherds are turned up in abundance by the plough. The loam has risen within the walls of his graveyards, as generation after generation has mouldered there into dust.

4. *On the Distribution of Life.*—It is under this head, perhaps, that the most subtle of human influences come. Some of man's doings in this domain are indeed plain enough, such as the extirpation of wild animals, the diminution or destruction of some forms of vegetation, the introduction of plants and animals useful to himself, and especially the enormous predominance given by him to the cereals and to the spread of sheep and cattle. But no such extensive disturbance of the normal conditions of the distribution of life can take place without carrying with it many secondary effects, and setting in motion a wide cycle of change and of reaction in the animal and vegetable kingdoms. For example, the incessant warfare waged by man against birds and beasts of prey in districts given up to the chase leads sometimes to unforseen results. The weak game is allowed to live, which would otherwise be killed off and give more room for the healthy remainder. Other animals which feed perhaps on the same materials as the game are by the same cause permitted to live unchecked, and thereby to act as a further hindrance to the spread of the protected species. But the indirect results of man's interference with the *régime* of plants and animals still require much prolonged observation.

From this brief and imperfect outline the reader may perceive that man takes an important place as a geological agent, and that in future ages the traces of his interference will introduce a new element of difficulty into the study of geological phenomena.

PART IV.—STRUCTURAL GEOLOGY,

OR THE ARCHITECTURE OF THE EARTH'S CRUST.

Having considered the nature of the materials constituting the crust of the earth, and the operation of the different agencies by which these materials are produced, arranged, and modified, we may now proceed to examine the structure of the crust itself with the view of marking how its component parts have been put together. Since by far the largest portion of the crust consists of sedimentary or

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[1] The reader will find much suggestive matter in Marsh's *Man and Nature*, a work which, as its title denotes, specially treats of this subject. A new and enlarged edition of this volume was published in 1874 under the title of *The Earth as Modified by Human Action.*

aqueous rocks, it will be of advantage to treat of them first, noting, in the first place, their original characters as resulting from the circumstances under which they were formed, and afterwards, the modifications subsequently effected upon them. Many of these superinduced structures, which are not peculiar to sedimentary, but occur more or less markedly in all rocks, may be conveniently described together. The distinctive characters of the igneous or eruptive rocks, as portions of the architecture of the crust will then be described; and lastly, those of the crystalline schists and other associated rocks to which the name of metamorphic is usually applied.

I. STRATIFICATION AND ITS ACCOMPANIMENTS.

The term "stratified," so often applied as a general designation to the aqueous or sedimentary rocks, expresses their leading structural feature. They are arranged in layers or strata, an arrangement characteristic of them alike in hand-specimens and in the cliffs of mountains. Not that every morsel of aqueous rock exhibits evidence of stratification. But it is this characteristic which is least frequently absent. The general aspects of stratification will be best followed in an explanation of the terms by which they are expressed.

Laminæ are the thinnest paper-like layers of deposit in a stratified rock. Such fine layers only occur where the material is fine-grained, as in mud or shale, or where fine scales of some mineral have been plentifully deposited, as in micaceous sandstone. In some laminated rocks the laminæ cohere so firmly that they can hardly be split open, and the rock will break more readily across them than in their direction. More usually, however, the planes of lamination serve as convenient divisional planes by means of which the rock can be split open. The frequency with which laminæ can be separated from each other, indicating, as it does, a failure of coherence between the layers of deposit, may probably be taken as a proof that these layers were originally laid down at intervals of sufficient duration to admit of a considerable amount of consolidation of one layer before the deposition of the next. It is quite possible that in many, if not in most cases, these intervals were of longer duration than those required for the successive deposit of the laminæ. In estimating therefore the length of time represented by say one foot of such finely laminated rock, we might reasonably regard the actual time occupied in deposition as only a small fraction of the whole interval.

The existence of laminæ points to tranquil conditions of slow intermittent deposit. The sediment has been borne at intervals and fallen over the same area of undisturbed water. Regularity of thickness and persistence of lithological character among the laminæ may be taken to indicate periodic currents, of approximately equal force, from the same quarter. In some cases successive tides in a sheltered estuary may have been the agent of deposition. In others the sediment was doubtless brought by recurring river-floods. A great thickness of laminated rock, like the massive shales of Palæozoic formations, points to a prolonged period of quiescence, and probably, in most cases, to slow, tranquil subsidence of the sea-floor. On the other hand, the alternation of thin bands of laminated rock with others coarser in texture and non-laminated suggests considerable oscillation of currents from different quarters bearing different qualities and amounts of sediment.

Strata or *Beds* are layers of rock varying from an inch or less up to many feet in thickness. A stratum may be made up of many laminæ, if the nature of the sediment and mode of deposit have favoured the production of this structure This has very commonly been the case where the sediment has been exceedingly fine-grained. Where the materials are of coarser grain, the strata, as a rule, are not laminated, but form the thinnest parallel divisions of the mass of rock. Strata, like laminæ, may either cohere firmly, or, as more usually happens, be separable with more or less ease from each other. In the former case we may suppose the upper to have followed the lower bed without the lapse of an interval long enough to allow of the consolidation of the latter. The common merging of a stratum into that which overlies it must no doubt be regarded as evidence of more or less gradual change in the conditions of deposit. Where the overlying bed shows no cohesion with that below it, the interval was probably of some duration. A stratum may be one of a series of similar beds in the same mass of rock. Thus a thick sandstone consists of many individual strata, varying it may be very considerably in their respective thicknesses. Or a stratum may be complete and distinct in itself, as where one of limestone or ironstone runs through the heart of a series of shales. As a general rule we may conclude that wherever among sedimentary accumulations stratification is exceedingly well-marked the rocks were formed rather slowly, and that where it is weak or absent the conditions of deposit were more rapid, without the intervals and changes necessary for the production of the distinctly stratified structure.

False-bedding, Current-bedding.—Some strata, particularly sandstones, are marked by an irregular lamination, wherein the laminæ, though for short distances parallel to each other, are oblique to the general stratification of the mass, at constantly varying angles and in different directions. The accompanying section (fig. 9) illustrates this structure, which is known by the name of false-bedding or current-bedding. The finer lines in this drawing represent the laminæ of deposit, the stronger lines mark successive surfaces on which these laminæ were laid down. Such a structure points to frequent changes in the direction of the currents by which the sediment was carried along and deposited. Sand pushed over the bottom of a sheet of water by varying currents tends to accumulate irregularly in bands and ridges, which often advance with a steep slope in front. The upper and lower surfaces of the bank or bed of sand may remain parallel with each other as well as with the underlying bottom, yet the successive laminæ composing it may lie at an angle of 30° or even more. We may illustrate this structure by the familiar formation of a railway embankment. The top of the embankment on which the permanent way is to be laid is kept level, but the advancing end of the earth-work shows a steep slope over which the workmen are constantly discharging waggon-loads of rubbish. Hence the embankment, if cut open longitudinally, would present a "false-bedded" structure, for it would be found to consist of many irregular layers inclined at a high angle in the direction in which the formation of the mound had advanced. In the accompanying figure (fig. 10) the water moving in the direction of the arrow may drop sand at *b*, which will correspond in lamination with the general stratification of the locality; but when the current reaches the steep front of one of the advancing sand sheets it will allow the sand to roll down the slope, and may continue to bring fresh supplies of sediment until the slope is gradually effaced. Now and then, however, instead of laying down sediment, a current of greater strength than usual may appear and sweep away portions of the sediment already deposited.

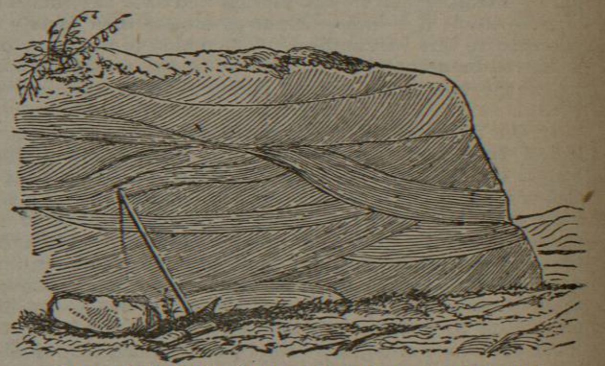

FIG 9.—Section of false-bedded strata on the coast of Waterford.[1]

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[1] The woodcuts in this Part are (with the exception of Nos. 20 and 31) from the article GEOLOGY in the last edition of the *Ency. Brit.*, written by the late J. B. Jukes, F.R.S.

FIG. 10.—Section illustrating the production of false-bedding.

Irregularities of Bedding due to Inequalities of Deposition or of Erosion.—A sharp ridge of sand or gravel may be laid down under water by current-action of some strength. Should the motion of the water diminish, finer sediment may be brought to the place and be deposited around and above the ridge. In such a case the stratification of the later accumulation will end off abruptly against the flanks of the older ridge, which will appear to rise up through the overlying bed. In fig. 11, for example, the lower bed seems to have been locally heaped up into the shape of a mound or ridge before the coal was accumulated over it. Appearances of this kind are not uncommon in some coal-fields, where they are known to the miners as "rolls," "swells," or "horses' backs." A structure exactly the reverse of the preceding occurs where a stratum has been scooped out before the deposition of the layers which cover it. This has often been observed in mining for coal. Channels have been cut out of a coal-seam, or rather out of the bed of vegetation which ultimately became coal, and these channels, ramifying and winding sometimes like those of streamlets on flat ground, have been filled up with sandy or muddy sediment. In fig. 12 a section is given of a remarkable series of such erosions, where beds of clay and sandstone have been extensively denuded in the intervals between the deposit of the successive beds. In these and similar cases it is evident that the erosion took place contemporaneously with the accumulation of the deposits as a whole. We cannot tell, of course, how long an interval elapsed between the formation of a given stratum and that of the next stratum which lies upon its eroded surface, nor how much depth of rock may have been removed in the erosion. When, however, as in the instances with which we are dealing, the structure occurs among conformable strata, evidently united as one lithologically continuous series of deposits, we may reasonably infer that the missing portions are of small moment and that the erosion was merely due to the irregular and more violent action of the very currents by which the sediment of the successive strata was supplied.

FIG. 11.—Mound of clay with ironstone balls (*a*), covered by beds of coal (*bb*).

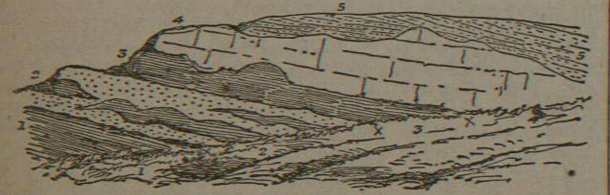

FIG. 12.—Section of New Red Sandstone, road-cutting near Wolverhampton. 1, Red and white clay or marl; 2, Brown sandstone with irregular patches of marl; 3, Red marl, partially eroded before the deposition of 4, Brown sandstone eroded before the formation of 5, Calcareous sandstone or cornstone.

The case is very different when the eroded strata are inclined at a different angle to those above them, and are strongly marked off by lithological distinctions. In some of the coal-mines in central Scotland, for instance, deep channels have been met with entirely filled with sand, gravel, or clay belonging to the general superficial drift of the country. These channels have evidently been water-courses worn out of the coal-measure strata at a comparatively recent geological period, and subsequently buried under the glacial accumulations. There is a complete discordance between them and the Palæozoic strata below, pointing to the existence of a vast interval of time.

Ripple-mark.—The surface of many beds of sandstone is marked with lines of wavy ridge and hollow, such as may be seen on any shore from which the tide has retired. This kind of surface is known as "ripple-mark." It may be formed on dry blown sand by the action merely of the wind, and it is of everyday occurrence under shallow water, not merely on sea-shores, but on the floors of lakes and of river-pools. The water, gently agitated by the wind in a given direction, throws the surface of the underlying sediment into ripples which tend to run at right angles to the course of movement. But as the wind veers from point to point, producing corresponding changes in the direction of the water-currents, the ripples on the bottom are not strictly parallel, but often coalesce, intersect, and undulate in their course. Their general direction, however, suffices to indicate the quarter whence the chief movement of the water has come. No satisfactory inference can be drawn from the existence of a rippled surface as to the depth of water in which the sediment was accumulated. As a rule it is in water of only a few feet or yards in depth that ripple-mark is formed. But it may be produced at any depth to which the agitation caused by wind on the upper waters may extend.

On an ordinary beach each tide usually effaces the ripple-marks made by its predecessor, and leaves a new series to be obliterated by the next tide. But where the markings are formed in water which is always receiving fresh accumulations of sediment, a rippled surface may be gently overspread by the descent of a layer of sediment upon it and may thus be preserved. Another series of ripples may then be made in the overlying layers, which in turn may be buried and preserved under a renewed deposit of sand. In this way a considerable thickness of such ripple-marked strata may be accumulated, as has frequently taken place among geological formations of all ages.

An examination of any sandy beach from which the sea has recently retired brings before us many modifications of the perfect ripple-mark. The ridges may be seen to grow more and more notched and irregular, until at last the beach seems to be dotted over with little, flat, dome-shaped mounds, or as if the ridges of the ripple-mark had been furrowed across. These modifications are doubtless due to the partial effacement of the ridges by subsequent action of the water agitated by wind from a different quarter. Such indications of shallow-water conditions may often be observed among old arenaceous deposits, as in the Cambrian and Silurian rocks. In like manner we may frequently detect, among these ancient formations, small isolated or connected linear ridges directed from some common quarter, like the current-marks frequently to be found behind projecting fragments of shell, stones, or bits of sea-weed on a beach from which the tide has just retired.

Sun-cracks, Rain-pittings, &c.—Proofs may not infrequently be found that during deposition aqueous strata have been laid bare to air and sun. The nature and validity of this evidence will be best ascertained by observations made at the margin of the sea, or of any inland sheet of water, which from time to time leaves tracts of mud or fine sand exposed to sun and rain. The way in which the muddy bottom of a dried-up pool cracks into polygonal cakes when exposed to the sun may be illustrated abundantly among geological formations of all ages. These desiccation-cracks, or sun-cracks, could not have been produced so long as the sediment lay under water. Their existence therefore among any strata proves that the surface of rock on which they lie was exposed to the air and dried before the next layer of water-borne sediment was deposited upon it.

With these markings are not infrequently associated prints of rain-drops. The familiar effects of a heavy shower upon a surface of moist sand or mud may be witnessed among rocks even as old as parts of the Cambrian system. In some cases the rain-prints are found to be ridged up on one and the same side in such a manner as to indicate that the rain-drops as they fell were driven along in a slanting direction. The prominent side of the markings therefore indicates the side towards which the wind blew.

Numerous proofs of shallow shore-water, and likewise of exposure to the air, are supplied by markings left by animals. Castings and trails of worms, tracks of mollusks and crustaceans, fin-marks of fishes, footprints of birds, reptiles, and mammals, may all be preserved and give their evidence regarding the physical conditions under which sedimentary formations were accumulated. It may frequently be noticed that such impressions are associated with ripple-marks, rain-prints, or sun-cracks; so that more than one kind of evidence may be gleaned from a locality to show that it was sometimes laid bare of water.

Gas-spurts.—The surfaces of some strata, usually of a dark colour and containing much organic matter, may be observed to be raised into little heaps of various indefinite shapes, not, like the heaps associated with worm burrows, connected with pipes descending into the rock, nor composed of different material from the surrounding sandstone or shale. These may be conjectured to be due to the intermittent escape of gas from the decomposing organic matter in the original sand or mud, as we may sometimes witness in operation among the mud flats of rivers and estuaries. On a small scale these protrusions of the upper surface of a deposit may be compared with the well-known mud-lumps at the mouths of the Mississippi, where the muddy bottom rises into mounds sometimes to a height of several yards above the water, from the top of which great quantities of carburetted hydrogen gas make their escape, together with water and mud.

Concretions.—Many sedimentary rocks are marked by the occurrence of concretions in them, either distinct in aspect and composition from the general mass of the rock, or forming really part of that mass, though separated from the rest by their being agglutinated into concretionary forms. Such concretions, where they differ in petrographical characters from the surrounding matter, are almost invariably of original or contemporaneous formation, that is, were formed at the same time as the strata among which they lie. Where, however, they appear to be merely compacted portions of the stratum, they may be regarded as generally due to some subsequent change effected upon the rock.

Contemporaneous concretions most commonly consist of carbonate of iron, carbonate of lime, or silica. Many clay-ironstone beds assume a nodular form, and this mineral occurs abundantly in the shape of separate nodules in shales and clay-rocks. The nodules have frequently formed round some organic body such as a fragment of plant, a shell, bone, or coprolite. That the carbonate of iron was slowly precipitated during the formation of the bed of shale in which its nodules lie may often be satisfactorily proved by the lines of deposit passing continuously through the nodules. In many cases the internal first-formed parts of a nodule have contracted more than the outer and more compact crust; and have cracked into open polygonal spaces which are commonly filled with calcite. Similar concretions of carbonate of lime occur in some clays and in connexion with limestones. Concretions of silica occur in limestone of many geological ages (see *ante*, p. 239). The flints of the English chalk are a familiar example, but similar siliceous concretions occur even in Lower Silurian limestones. The silica in these cases has not infrequently been deposited round organic bodies such as sponges, sea-urchins, and mollusca, which are completely enveloped in it and have even themselves been silicified. Iron-bisulphide (pyrite or marcasite) often assumes the form of concretions, more particularly among clay-rocks, and these, though presenting many eccentricities of shape, round like pistol-shot or cannon-balls, kidney-shaped, botryoidal, &c., agree in usually possessing an internal fibrous radiated structure. Phosphate of lime is found as concretions in formations where the coprolites and bones of reptiles and other animals have been collected together.


FIG. 13.—Sketch of limestone-beds, with concretions of white chert, Middleton Moor, Derbyshire.

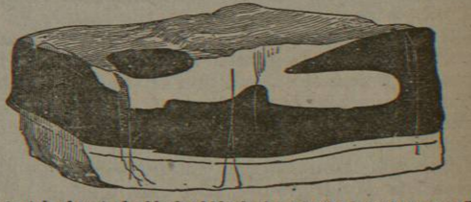
FIG 14.—Sketch of part of a block of black chert in the limestone near Dublin.

Concretions produced subsequently to the formation of the rock may be observed in some sandstones, which, when exposed to the weather, decompose into large round balls. Some shales exhibit this structure in a still more striking manner, inasmuch as the concretions consist of the general mass of the laminated shale, and the lines of stratification pass through them and mark them out distinctly as superinduced upon the rock. Some magnesian limestones are so concretionary as to resemble masses of conglomerate; yet the concretions, among all their fantastic shapes and with their acquired crystalline texture, may often be found to retain traces of the original stratification of the rock. Beds of rock-salt may likewise be observed to be marked with traces of a concretionary arrangement.

Order of Superposition—the Foundation of Geological Chronology.—As sedimentary strata are laid down upon one another in a more or less nearly horizontal position, the underlying beds must be older than those which cover them. This simple and obvious truth is termed the law of superposition. It furnishes the means of determining the chronology of rocks, and though other methods of ascertaining this point are employed, they must all be based originally upon the observed order of superposition. The only case where the apparent superposition may be deceptive is where the strata have been inverted. In the Alps, for example, the rocks composing huge mountain masses have been so completely overturned that the highest beds appear as if regularly covered by others which ought properly to underlie them. But these are exceptional occurrences, where the true order can usually be made out from other sources of evidence.

Alternations of Strata.—Though great variations occur in the nature of the strata composing a mass of sedimentary rocks, it may often be observed that certain repetitions occur. Sandstones, for example, are found to be interleaved with shale above, and then to pass into shale; the latter may in turn become sandy at the top and be finally covered by sandstone, or may assume a calcareous character and pass up into limestone. Such alternations bring before us the conditions under which the sedimentation took place. A sandstone group indicates water of comparatively little depth, moved by changing currents, bringing the sand now from one side now from another. The passage of such a group into one of shale points to a diminution in the motion and transporting power of the water, perhaps to a sinking of the tract, whereby only fine mud was then intermittently brought into it. The advent of a limestone above the shale serves to show that the water cleared, owing to a deflexion of the sediment-carrying currents, or to continued and perhaps more rapid subsidence, and that *Foraminifera*, corals, crinoids, *Mollusca*, or other lime-secreting organisms, established themselves upon the spot. Shale overlying the limestone would tell of fresh inroads of mud, which destroyed the animal life that had been flourishing on the bottom; while a return of sandstone beds would mark how, in the course of time, the original conditions of troubled currents and shifting sandbanks returned. Such alternating groups of sandy, calcareous, and argillaceous strata are well illustrated among the Jurassic formations of England.

Associations of Strata.—Certain kinds of strata very commonly occur together, because the conditions under which they were formed were apt to arise in succession. One of the most familiar examples is the association of coal and fire-clay. A seam of coal is almost invariably found to lie on a bed of fire-clay, or on some argillaceous stratum. The reason of this union becomes at once apparent when we learn that the fire-clay formed the soil on which the plants grew that went to form the coal. Where the clay was laid down under suitable circumstances vegetation sprang up upon it. Again conglomerate and sandstone occur together rather than conglomerate and shale, because the agitation of the water which could form and deposit coarse detritus, like that composing conglomerate, was too great to admit of the accumulation of fine silt. For a similar reason we may look for shale or clay rather than sandstone as an accompaniment of limestone.

Relative Persistence of Strata.—Observation of what takes place on any lake bottom, estuary, or sea-margin teaches that some kinds of sediment are much more widely spread than others, and prepares us to find that the same has been the case in past time, and therefore that some kinds of sedimentary rocks possess far greater persistence than others. As a general rule it may be said that the coarser the grain the more local the extent of a rock. Conglomerates are thus by much the most variable and inconstant of all sedimentary formations. They suddenly sink down from a thickness of several hundred feet to a few yards, or die out altogether, to reappear perhaps further on, in the same wedge-like or lenticular fashion. Sandstones are less liable to such extremes of inconstancy, but they too are apt to thin away and to swell out again. Shales are much more persistent, the same zone being often traceable for many miles. Limestones sometimes occur in thick local masses, as among the Silurian formations of Wales and Scotland, but they often also display remarkable continuity. Three thin limestone bands, each of them only 2 or 3 feet in thickness, and separated by a considerable thickness of intervening sandstones and shales, can be traced through the coal-fields of central Scotland over an area of at least 1000 square miles. Coal-seams also possess great persistence. The same seams, varying slightly in thickness and quality, may often be traced thoughout the whole of an extensive coal-field.

What is thus true of individual strata may be affirmed also of groups of such strata. A thick mass of sandstone will be found as a rule to be more continuous than one of conglomerate, but less so than one of shale. A series of limestone-beds will usually be found to stretch further than either of them. But even to the most extensive stratum or group of strata there must be a limit. It must end off and give place to others, either suddenly, as a bank of shingle is succeeded by the sheet of sand heaped against its base, or very gradually, by insensibly passing into other strata on all sides.

Great variations in the character of stratified rocks may frequently be observed in passing from one part of a country to another along the outcrop of the same rocks. Thus at one end we may meet with a thick series of sandstones and shales which, traced in a certain direction, may be found passing into limestones. A group of strata may consist of massive conglomerates at one locality, and may graduate into fine fissile flagstones in another. A thick mass of clay may be found to alternate more and more with shelly sands as it is traced outward, until it loses its argillaceous nature altogether. No difficulty need be felt in admitting the strict contemporaneity of these diverse layers of sediment. At the present time we see how coarse shingle may be formed along the beach at the same time that the finest mud is being laid down on the same sea-bottom further from land. Could we raise up that bottom, we should doubtless find as gradual a passage from the littoral to the deeper water deposits as we do among the geological formations of the earth's crust. The existing differences of character between the deposits of the shore and of the opener sea would no doubt continue to be maintained, with slight geographical displacements, even if the whole area were undergoing subsidence, giving rise to a thick group of littoral beds in one tract and of deeper-water accumulations at another. In like manner among the formations of former geological periods the same conditions of deposit appear sometimes to have continued for a considerable period. Hence the thick Mountain or Carboniferous Limestone of Derbyshire is gradually replaced northwards by the thick sandstone shales, ironstones, and coal-seams of Scotland.

Overlap.—When strata have been laid down in a subsiding region wherein the area of deposit gradually increased, the sediment must have spread over a progressively augmenting surface. By this means the later portions of a sedimentary series will extend beyond the limits of the older parts, and will repose directly upon the shelving bottom, with none of those older strata underneath them. This relation is called Overlap (see fig. 59). The higher or newer members are said to overlap the older. This structure may often be detected among formations of all geological ages. It brings before us the shore line of ancient land-surfaces, and shows how, as these sank under water, the gravels, sands, and silts gradually advanced and covered them.

Relative Lapse of Time represented by Strata and by the Intervals between them.—Of the absolute length of time represented by any strata or groups of strata we can form no satisfactory estimates. Certain general conclusions may indeed be drawn, and comparisons may be made between different series of rocks. Sandstones full of false-bedding were probably accumulated more rapidly than finely-laminated shales or clays. It is not uncommon in certain Carboniferous formations to find huge coniferous trunks imbedded in an inclined position in sandstone. These trees seem to have been carried along and to have sunk, their heavier or root-end touching the bottom, and their upper end pointing upward in the direction of the current, exactly as in the case of the snags of the Mississippi. The continuous deposit of sand at last rose above the level of the trunks and buried them. It is clear then that the rate of deposit must have been sufficiently rapid to have allowed a mass of 20 or 30 feet of sand to accumulate before the decay of the wood; though modern instances are known where, under certain circumstances, submerged trees may last for some centuries. Continuous layers of the same kind of deposit suggest a persistence of geological conditions; numerous alternations of different kinds of sedimentary matter point to vicissitudes or alternations of conditions. As a rule, we should infer that the time represented by a given thickness of similar strata was less than that shown by the same thickness of dissimilar strata, because the changes needed to bring new varieties of sediment into the area of deposit would usually require the lapse of some time for their completion. But this conclusion might often be erroneous. It would be best supported when, from the very nature of the rocks, wide variations in the character of the water-bottom could be established. Thus a group of shales followed by a fossiliferous limestone would almost always mark the lapse of a much longer period than an equal depth of sandy strata. Limestones made up of organic remains which lived and died upon the spot, and whose remains are crowded together generation above generation, must have demanded many years for their formation.

But in all speculations of this kind we must bear in mind that the length of time represented by a given depth of strata is not to be estimated merely from their thickness or lithological characters. It has already been pointed out that the interval between the deposit of two successive laminæ of shale may have been as long as, or even longer than, that required for the formation of one of the laminæ. In like manner, the interval needed for the transition from one stratum or kind of strata to another may often have been more than equal to the time required for the formation of the strata on either side. But the relative chronological importance of the bars or lines in the geological record can seldom be satisfactorily discussed merely on lithological grounds. This must mainly be decided on the evidence of organic remains, as will be shown in part v. By this kind of evidence it can be made nearly certain that the intervals represented by strata were in many cases much shorter than those not so represented,—in other words, that the time during which no deposit of sediment went on was longer than that wherein deposit did take place.

Groups of Strata.—Passing from individual strata to large masses of stratified rock, the geologist finds it needful for convenience of reference to subdivide these into groups. He avails himself of two bases of classification—(1) lithological characters, and (2) organic remains.

1. The subdivision of stratified rocks into groups according to their mineral aspect is an obvious and easily applied classification. Moreover, it often serves to connect together rocks formed continuously in certain circumstances which differed from those under which the strata above and below were laid down,—so that it expresses natural and original subdivisions of strata. In the middle of the English Carboniferous system of rocks, for example, a zone of sandy and pebbly beds occurs, known as the Millstone Grit. No abrupt and sharp line can be drawn between these strata and those above and below them. They shade upward and downward into the beds between which they lie. Yet they form a conspicuous belt, traceable for many miles by the scenery to which it gives rise. The red rocks of central England, with their red sandstones, marls, rock-salt, and gypsum, form likewise a well-marked group or rather series of groups. It is obvious, however, that characters of this kind, though sometimes wonderfully persistent over wide tracts of country, must be at best but local. The physical conditions of deposit must always have been limited in extent. A group of strata showing great thickness in one region will be found to die away as it is traced into another. Or its place is gradually taken by another group which, even if geologically contemporaneous, possesses totally different lithological characters. Just as at the present time a group of sandy deposits gradually gives place along the sea-floor to others of mud, and these to others of shells or of gravel, so in former geological periods contemporaneous deposits were not always lithologically similar. Hence mere resemblance in mineral aspect usually cannot be regarded as satisfactory evidence of contemporaneity except within comparatively contracted areas. The Carboniferous Limestone of Ireland is a thick calcareous group of rocks, full of corals, crinoids, and other organisms, which bear witness to the formation of these rocks in the open sea. But if these limestones, with their characteristic marine fossils, are traced into the north of England and Scotland, they are found to pass into sandstones and shales, with numerous coal-seams, and only a few thin beds of limestone. The soft clay beneath the city of London is represented in the Alps by hard schists and contorted limestones. We conclude therefore that lithological agreement when pushed too far is apt to mislead us, partly because contemporaneous strata often vary greatly in their lithological character, and partly because the same lithological characters may appear again and again in different ages. By trusting too implicitly to this kind of evidence, we may be led to class together rocks belonging to very different geological periods, and on the other hand to separate groups which really, in spite of their seeming distinction, were formed contemporaneously.

2. It is by the remains of plants and animals imbedded among the stratified rocks that the most satisfactory subdivisions of the geological record can be made, as will be more fully stated in parts v. and vi. A chronological succession of organic forms can be made out among the rocks of the earth's crust. A certain common facies or type of fossils is found to characterize particular groups of rock, and to hold true even though the lithological constitution of the strata should greatly vary. Moreover, though comparatively few species are universally diffused, they possess remarkable persistence over wide areas, and even when they are replaced by others, the same general facies of fossils remains. Hence the stratified formations of two countries geographically distant, and having little or no lithological resemblance to each other, may be compared and paralleled zone by zone, simply by means of their enclosed organic remains.

II. Joints.

All rocks are traversed more or less distinctly by vertical or highly inclined divisional planes termed *Joints*. Soft rocks indeed, such as loose sand and uncompacted clay, do not show these lines; but wherever a mass of clay has been subjected to some pressure and consolidation, it will usually be found to have acquired them. It is by means of the intersection of joints that rocks can be removed in blocks; the art of quarrying consists in taking advantage of these natural planes of division. Joints differ in character according to the nature of the material which they traverse; those in sedimentary rocks are usually distinct from those in crystalline masses.

1. *In Sedimentary Rocks.*—Joints vary in sharpness of definition, in the regularity of their perpendicular and horizontal course, in their lateral persistence, in number, and in the directions of intersection. As a rule, they are most sharply defined in proportion to the fineness of grain of the rock. In limestones and close-grained shales, for example, they often occur so clean-cut as to be invisible until revealed by fracture or by the slow disintegrating effects of the weather. The rock splits up along these concealed lines of division whether the agent of demolition be the hammer or frost. In coarse-textured rocks, on the other hand, joints are apt to show themselves as irregular rents along which the rock has been shattered, so that they present an uneven sinuous course, branching off in different directions. In many rocks they descend vertically in straight lines at not very unequal distances, so that the spaces between them are thus marked off into so many wall-like masses. But this symmetry often gives place to a more or less tortuous course with lateral joints in various random directions, more especially where the different strata vary considerably in lithological characters. A single joint may be traced sometimes for many yards, or even for several miles, more particularly when the rock is fine-grained, as in limestone. But where the texture is coarse and unequal, the joints, though abundant, run into each other in such a way that no one in particular can be identified for so great a distance. The number of joints in a mass of stratified rock varies within wide limits. Among strata which have undergone little disturbance the joints may be separated from each other by intervals of several yards. But in other cases where the terrestrial movement appears to have been considerable, the rocks are so jointed as to have acquired therefrom a fissile character that has nearly or wholly obliterated their tendency to split along the lines of bedding.

An important feature in the joints of stratified rocks is the direction in which they intersect each other. As the result of observation we learn that they possess two dominant trends, one coincident in a general way with the direction in which the strata are inclined to the horizon, and the other running transversely at a right angle or nearly so. The former set is known as *dip-joints*, because they run with the *dip* or inclination of the rocks, the latter is termed *strike-joints*, inasmuch as they conform to the general *strike* or mean outcrop. It is owing to the existence of this double series of joints that ordinary quarrying operations can be carried on. Large quadrangular blocks can be wedged off, which would be shattered if exposed to the risk of blasting. A quarry is usually worked to the dip of a rock, hence the strike-joints form clean-cut faces in front of the workmen as they advance. These are known as "backs," and the dip-joints which traverse them as "cutters." The way in which this double set of joints occurs in a quarry may be seen in fig. 15, where the parallel lines which traverse the shaded and unshaded faces mark the successive strata. The broad white spaces running along the length of the quarry behind the seated figure are strike-joints or "backs," traversed by some highly inclined lines which mark the position of dip-joints or "cutters." The shaded ends looking towards the spectator are "cutters" from which the rock has been quarried away on one side.

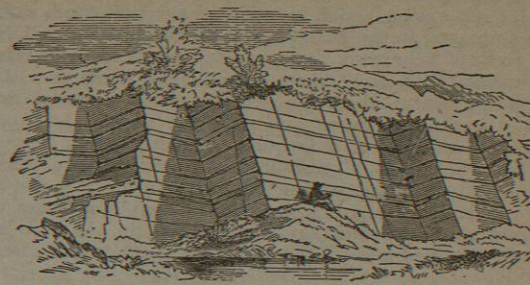

FIG. 15.—Joints in limestone quarry near Mallow, co. Cork. (G. V. Du Noyer.)

In some conglomerates the joints may be seen traversing the enclosed pebbles as well as the surrounding matrix. Large blocks of hard quartz are cut through by them as sharply as if they had been sliced in a lapidary's machine, and the same joints can be traced continuously through many yards of the rock. Such facts show that the agency to which the jointing of rocks was due must have operated with considerable force.[1] Further indication of movement is often supplied by the rubbed and striated surfaces of joints. These surfaces, termed *slickensides*, have evidently been ground against each other. They are often coated with hæmatite, calcite, chlorite, or other mineral, which has taken a cast of the striæ and then seems itself to be striated.

Joints form natural lines for the passage downward and upward of subterranean water. They likewise furnish an effective lodgment for surface water which, frozen by a lowering of temperature, expands into ice, and wedges off blocks of rock in the manner already described. As they serve, in conjunction with bedding, to divide stratified rocks into large quadrangular blocks, their effect on cliffs and other exposed masses of rock is seen in the apparently splintered, dislocated aspect so familiar in mountain scenery.

Occasionally a prismatic or columnar form of joints may be observed among stratified rocks. When this occurs among unaltered strata it is usually among those which have been chemically formed, as in gypsum, where, as observed by Mr Jukes in the Paris Basin, some beds are divided from top to bottom by vertical hexagonal prisms. A columnar structure has often been superinduced upon stratified rocks by contact with intrusive igneous masses. Sandstones, shale, and coal may be observed in this condition. The columns diverge perpendicularly to the surface of the injected and altering substance, so that when the later is vertical the columns are horizontal, or when it undulates the columns follow its curvatures. Beautiful examples of this character occur among the coal-seams of Ayrshire.

2. *In Crystalline (Igneous) Rocks.*—While in stratified rocks the divisional planes consist of lines of bedding and of joint, cutting each other usually at a high if not a right angle, in massive igneous rocks they include joints only; and as these do not as a rule present the same parallelism as lines of bedding, unstratified rocks, even though as full of joints, have not the same regularity of arrangement as in the stratified formations. Granite, for example, is traversed by two sets of chief or "master-joints," cutting each other somewhat obliquely. Their effect is to divide the rock into long quadrangular, rhomboidal, or even polygonal columns.

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[1] See an interesting series of experiments by M. Daubrée (*Comptes Rendus*, lxxxvi., 1878) on the production of faults and joints.