Section VI.

GEOLOGY.

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A person embarked on a naval expedition, who wishes to attend to Geology, is placed in a position in some respects highly advantageous, and in others as much to the contrary. He can hardly expect during his comparatively short visits at one place, to map out the area and sequence of widely extended formations; and the most important deductions in geology must ever depend on this having been carefully executed; he must generally confine himself to isolated sections and small areas, in which, however, there can be no doubt many interesting facts may be collected. On the other hand, he is admirably situated for studying the still active causes of those changes, which, accumulated during long-continued ages, it is the object of geology to record and explain. He is borne on the ocean, from which most sedimentary formations have been deposited. During the soundings which are so frequently carried on, he is excellently placed for studying the nature of the bottom, and the distribution of the living organisms and dead remains strewed over it. Again, on sea-shores, he can watch the breakers slowly eating into the coast-cliffs, and he can examine their action under various circumstances: he here sees that going on in an infinitesimally small scale, which has planed down whole continents, levelled mountain-ranges, hollowed out great valleys, and exposed over wide areas rocks, which must have been formed or modified whilst heated under an enormous pressure. Again, as almost every active volcano is situated close to, or within a few leagues of the sea, he is admirably situated for investigating volcanic phenomena, which in their striking aspect and simplicity, are well adapted to encourage him in his studies.

In the present state of the science, it may be doubted whether the mere collection of fragments of rock without some detailed observations on the district whence they are brought, is worthy of the time consumed and the carriage of the specimens. The simple statement that one part of a coast consists of granite, and another of sandstone or clay-slate, can hardly be considered of any service to geology; and the labour thus thrown away might have been more profitably spent, and thus saved the collector much ultimate disappointment. It is now generally recognized that both the sedimentary rocks, and those which have come from below in a softened state, are nearly the same over the whole world. A mere fragment, with no other information than the name of the place where collected, tells little more than this fact. These remarks do not at all apply to the collection of fossil remains, on which subject some remarks will presently be made; nor do they apply to an observer collecting suites of rock-specimens, with the intention of himself subsequently drawing up an account of the structure and succession of the strata in the countries visited. For this end, he can hardly collect too copiously, for errors in the naming of the rocks may thus be corrected, and the careful comparison of such specimens will often reveal to him curious relations which at the time he did not suspect.

In order to make observations of value, some reading and much careful thought are necessary; but perhaps no science requires so little preparatory study as geology, and none so readily yields, especially in foreign countries, new and striking points of interest. Some of the highest problems in geology wait on the observer in distant regions for explanation; such as, whether the successive formations, as judged of by the character of their fossil remains, correspond in distant parts of the world to those of Europe and North America, or whether some of them may not correspond to blank epochs of the north, when sedimentary beds either were not there accumulated, or have been subsequently destroyed. Again, whether the lowest formation everywhere is the same with that in which living beings are first present in the countries best known to geologists. These and many other such wide views in the history of the world are open to any one, who, applying thought and labour to his subject, has the good fortune to geologise in little frequented countries.

A person wishing to commence geology, is often deterred by not knowing the names of the rocks; but this is a knowledge, he may rely on it, easily acquired. With half a dozen named crystalline rocks, or even by patiently familiarizing his eye (aided by a lens) to the aspect of the feldspar and quartz in granite, he will know the two most essential ingredients in most igneous rocks; and in granite he will often find the glittering scales of mica replaced by a dark green mineral, less hard than the feldspar and quartz; and then he will know the third most important mineral, hornblende. The sedimentary rocks can hardly be described, except by the terms in common use: impure limestone, which cannot be readily recognized by the eye, can be distinguished by its effervescence with acids. By the repeated comparison of freshly fractured sedimentary and igneous rocks, such as sandstone and clay-slate on the one hand, and granite and lava on the other, he will learn the difference between crystalline and mechanical structure; and this is a very necessary point. Let no one be deterred from geology by the want of mineralogical knowledge; many excellent geologists have known but little; and from this reason its value has perhaps sometimes been underrated, for many of the obscurer points in geology, such as the nature of the metamorphic changes in rocks, and all the phenomena of metallic and other veins, almost require such knowledge. The appearances presented by the different forms of stratification (that is, the original planes of deposition) may be soon learnt in the field; though no doubt the beginner would be aided by the diagrams given in many elementary works.

The two most useful works which the geologist can carry with him, are without doubt the 'Principles' and the 'Elements of Geology,' by Sir Charles Lyell. He should procure a treatise on mineralogy, for instance, 'Phillips's Mineralogy,' by Allan. If he has the opportunity to procure others, Sir H. Delabeche's 'Researches in Theoretical Geology' would be particularly desirable from discussing many of the questions which ought especially to engage the attention of a sea voyager. As he will probably visit many volcanic regions, Dr. Daubeny's 'Treatise on Volcanos' would be extremely useful; and a list is there given of special treatises on the volcanic countries likely to be visited by him. The 'Description Physique des Isles Canaries,' by Von Buch, may be cited as a model of descriptive powers. The voyager in the Temperate and Polar regions ought to have Agassiz' work on Glaciers.

The geologist fortunately requires but little apparatus; a heavy hammer, with its two ends wedge-formed and truncated; a light hammer for trimming specimens; some chisels and a pickaxe for fossils; a pocket-lens with three glasses (to be incessantly used); a compass and a clinometer, compose his essential tools. One of the simplest clinometers is that constructed by the Rev. Prof. Henslow: it consists of a compass and spirit-level, fitted in a small square box; in the lid there is a brass plate, graduated in a quadrant of 90 degrees, with a little plumb-line to be suspended from a milled head at the apex of the quadrant. The line of intersection of the edge of the clinometer, when held horizontally, with the plane of the stratum, gives its strike, range, or direction; and its dip or inclination, taken at right angles to the strike, can be measured by the plumb-line. In an uneven country, it is not easy without the clinometer to judge which is the line of greatest inclination of a stratum; and it is always more satisfactory to be certain of the angle than to estimate it. A flat piece of rock representing the general slope can usually be found, and by placing a note-book on it, the measurement can be made very accurately. In studying the cleavage or slaty structure of rocks, accurate observations are indispensable. A mouth blow-pipe with its apparatus, and a book with instructions for its use (Phillips's Mineralogy contains brief directions), teaches a little mineralogy in a pleasant manner. Besides the above instruments, a mountain barometer is often very necessary: a portable level would, in the case of raised sea-beaches and terraces, be useful. Messrs. Adie and Son, of Edinburgh, sell a hand-level, a foot in length, which is fitted with a little mirror on a hinge, so that the observer, whilst looking along the level, can see when the bubble of air is central, and thus instantly find his level in the surrounding district. This is a very valuable instrument. Mr. R. Chambers, moreover, and others have found, that an observer having previously ascertained the exact height of his eye when standing upright, can measure the altitude of any point with surprising accuracy; he has only to mark by the level some recognizable stone or plant, and then to walk to it, repeat the process, and keep an account how many times the levelling has been repeated in ascending to the point, the height of which he wishes to ascertain.

A few cautions may be here inserted on the method of collecting. Every single specimen ought to be numbered with a printed number (*those which can be read upside down having a stop after them*) and a book kept exclusively for their entry. As the value of many specimens entirely depends on the stratum or locality whence they were procured being known, it is highly necessary that every specimen should be ticketed on the same day when collected. If this be not done, in after years the collector will never feel an absolute certainty that his tickets and references are correct. It is very troublesome ticketing every separate fossil from the same stratum, yet it is particularly desirable that this should be done; for when the species are subsequently compared by naturalists, mistakes are extremely liable to occur; and it should always be borne in mind, that misplaced fossils are far worse than none at all. Pill-boxes are very useful for packing fossils. Masses of clay or any soft rock may be brought home, if small fossil shells are abundant in them. Rock-specimens should be about two or three inches square, and half an inch thick; they should be folded up in paper. To save subsequent trouble, it will be found convenient to pack up and mark outside, sets of specimens from different localities. These details may appear trifling; but few are aware of the labour of opening and arranging a large collection, and such have seldom been brought home without some errors and confusion having crept in.

To a person not familiar with geological inquiry, on first landing on a new coast, probably the simplest way of setting to work, is for him to imagine a great trench cut across the country in a straight line, and that he has to describe the position (that is, the angle of the dip and direction) and nature of the different strata or masses of rock on either side. As, however, he has not this trench or section, he must observe the dip and nature of the rocks on the surface, and take advantage of every river-bank or cliff where the land is broken, and of every quarry or well, always carrying the beds and masses in his mind's eye to his imaginary section. In every case this section ought to be laid down on paper, in as nearly as possible the real proportional scale, copious notes should be made, and a large suite of specimens collected for *his own* future examination. The value of sections, with their horizontal and vertical scales true to nature, cannot be exaggerated, and their importance has only lately been appreciated to the full extent. The habit of making even in the rudest manner sectional diagrams is of great importance, and ought never to be omitted: it often shows the observer palpably and before it is too late (a grief to which every sea-voyager is particularly liable), where his knowledge is defective. Partly for the same reason, and partly from never knowing, when first examining a district, what points will turn out the most important, he ought to acquire the habit of writing very copious notes, not all for publication, but as a guide for himself. He ought to remember Bacon's aphorism, that "Reading maketh a full man, conference a ready man, and *writing an exact man*;" and no follower of science has greater need of taking precautions to attain accuracy; for the imagination is apt to run riot when dealing with masses of vast dimensions and with time during almost infinity. After the observer has made a few traverses of the country and drawn his sections (and the coast-cliffs often afford him an invaluable one), he will be himself astonished how, in the most troubled country, over which the surface has been broken up and re-cemented, almost like the fragments of ice on a great river, how all the parts fall into intelligible order. He will in his mind see the beds first horizontally stretched out one over the other in a fixed order, and he will then perceive that all the disturbance has arisen from a few nearly straight cracks, on the edges of which the beds have been upturned, and between which he will sometimes find great wedges of once heat-softened, but now crystalline rocks. He will find that large masses of strata have been removed and denuded, that is ground down into pebbles and mud, and long ago drifted away to form in some other area newer strata. He will now have a good idea of the physical structure of his district; and this much can be acquired with much greater facility than he will at first readily anticipate.

In examining a district to make a section, many minor points of detail will occur for observation, which can hardly be specified; such as the nature and cause of the transitions and alterations of the different strata, the source of the sediment and pebbles, the alterations in chemical nature, either of the whole mass, or of parts, as in concretions; the presence, and grouping and state of the fossil remains; the depth and condition of the old sea-bottom, when the beds were deposited, and an infinity of similar points. Probably the best method of obtaining this power of observation, is to acquire the habit of always seeking an explanation of every geological point met with; for one mental query leads on to another, and this will at the same time give interest to his researches, and will lead him to compare what is before his eyes, with all that he has read of or seen. With his increasing knowledge he will daily find his powers of observation, his very vision, become deeper and clearer. No one, however, must expect to solve the many difficulties which will be encountered, and which for a long time will remain to perplex geologists; but a ray of light will occasionally be his reward, and the reward is ample.

Organic Remains.—In the sectional diagram which we have supposed to be made, the simple superposition of the beds gives their relative antiquity: but the best section which a sea-voyager can hope to make, will seldom include but a small portion of the long sequence of known geological formations. And as the voyager seldom passes over large districts, he will rarely succeed in placing in proper order, by the aid of superposition alone, the formations which he successively meets with even in the same country. Hence he must, more than any other geologist, rely on the characters of the embedded organic remains, and must sedulously collect every specimen and fragment of a specimen. By the means of fossil remains, not only will he be enabled to arrange (with the help of naturalists on his return home) the formations in the same country according to their age, but their contemporaneity with the deposits of the most distant parts of the world can thus and by no other method be ascertained; for it is now known that at each geological epoch the marine animals partook in the most distant quarters of a general similarity, even when none of the species were identically the same: thus beds have been recognized in North and South America, and in India, which must have been deposited when the chalk in Europe was accumulating beneath the sea.

It is highly necessary most carefully to keep the fossils found in different strata separate; it will often occur in passing upwards from one bed to another, and occasionally even without any great change in the character of the rock, that the fossils will be wholly different; and if such distinct sets of fossils are mingled together, as if found together, undoubtedly it would have been better for the progress of science that they had never been collected. As there is some inconvenience in keeping the fossils collected on the same day separate, this caution is the more requisite. The collector, if he be not an experienced naturalist, should be very cautious in rejecting specimens, from thinking them the same with what he has already got; for it requires years of practice to perceive at once the small, but constant, distinctions which often separate species: the same species, moreover, if collected in different localities, or in beds one placed far above the other, are generally more valuable to the geologist than new species.

In formations from a few hundred to a thousand feet and upwards in thickness, the whole of which does actually belong to the same geological age, and is therefore characterized by the same fossils, most curious and important results may be sometimes deduced, if the position or relative heights at which the groups of fossils are embedded be noted; and this is a point usually neglected. For, thanks to the researches of Professor E. Forbes, the depth of water under which a collection of shells lived can now be approximately told; and thus the movement of the crust of the earth, whilst the strata including the shells were accumulating, can be inferred. For instance, if at the bottom of a cliff, say 800 feet in height, a set of shells are buried, which must have lived under water only 50 or 100 feet in depth; it is clear that the bottom of the sea must have sunk to have allowed of the deposition of the 700 feet of superincumbent submarine strata; subsequently the whole 800 feet must have been upraised. For this same purpose, and for other ends, it is desirable that it should be noted which species are the most numerous, and whether layers are composed exclusively of single kinds. It should be also remarked, whether the more delicate bivalve shells retain their two valves united, and whether the burrowing kinds are embedded in their natural positions, as these facts show that the shells have not been drifted from afar. Where there are fossil corals, it should be observed whether the greater number of specimens are upright, in the positions in which they grew. The remark formerly made that the collection of mere fragments of rock is of little or no use to geology, is far from applicable to fossil remains. Every single fossil species, bones, shells, crustacea, corals, impressions of leaves, petrified wood, &c., should be collected, and it is scarcely possible to collect too many specimens. Even a single species without any information of any kind, if it prove a quite new form, will be valuable to the zoologist; if it prove identical with, or closely allied to a known species, it may interest the geologist. A set of fossils, however, and still more several sets, with their superposition known, cannot fail to be of the highest value; they will tell the age of the deposit, and perhaps give the key to the whole geology of the country: some of the highest problems in this science wait for solution on large collections of species carefully made in distant regions.

A collection of recent shells (both those living on the coast and those to be procured by the dredge off it) from the same country or island at which a collection of tertiary fossil shells is made, is generally of very great service to the palæontologist, who undertakes the description of the fossils. The collecting recent shells will, moreover, with the aid of a little study, teach the geologist some conchology, and this is an acquirement yearly becoming more necessary: the geologist should exert himself to learn some general zoology.

The bones of vertebrated animals are much more rarely found than the remains of the lower marine animals, and they are almost in proportion more valuable. A person not acquainted with the science will hardly be able to imagine the deep interest which the discovery of a skeleton, if of higher organization than a fish, in any of the oldest formations would most justly create. The age of such a formation would have to be judged of by the co-embedded shells, and therefore, if possible, part of the slab containing the bones should include one or two shells to demonstrate their contemporaneity. Bones, however, from any formation are sure to be valuable; even a single tooth, in the hands of a Cuvier or Owen, will unfold a whole history; the heads, jaws, and articular surfaces are the most valuable; but every fragment should be brought home. Where bones are found close together, and especially if some of the parts lie in their natural positions, they should be packed together. Every bone, if found even six inches beneath the black vegetable mould, should be collected; there can be no doubt that many most valuable relics have been neglected, from the supposition that they belonged to still living animals. Low cliffs of mud, gravel, and clay on the banks of streams and on sea-shores (as well as in bared reefs extending from them), are the most likely places for the discovery of the remains of quadrupeds. Gravel beds under streams of lava; fissures in volcanic rocks; peat beds, and the clay or marl underlying peat, are all favourable places. Fishes' bones are found occasionally in all sedimentary strata, and are highly interesting.

Caverns.—These most frequently occur in limestone rocks, and they have yielded a truly wonderful harvest of remains in Europe, South America, and Australia. The bones generally occur in mud, under a stalagmitic crust produced by the dripping of the lime-charged water, which requires being broken up by a pickaxe. As caverns have often been used by wild races of man as places of habitation and burial, a most careful examination should be made to detect any signs of the surface having been anciently broken up near where the bones are found. Even small islands, not now inhabited by any land quadruped, if not very distant from a continent, are almost as likely to contain osseous remains as larger tracts of land. The interest of the discovery of the remains of land quadrupeds in an oceanic island would be extreme: for instance, it has been stated that the tooth of a mastodon has been found in one of the Azores; if this were confirmed, few geologists would doubt that these islands had once been united to Europe, thus enlarging wonderfully our ideas of the ancient geography of the Atlantic: so also the remains of a mastodon are said to have been brought from Timor, thus perhaps indicating the road by which this great quadruped formerly reached Australia.

Fossil Footsteps.—As allied to organic remains, fossil footsteps may be here referred to. They have been observed in Europe and North America, but hitherto in no other part of the world. These curious vestiges not only proclaim the former existence of reptiles and birds at very remote periods, and in rocks often not containing a fragment of bone, but they generally prove that the level of the land subsided after the animal had left its impress on the ancient sea-beach, thus allowing thousands of feet of strata to be thrown down over them. The best place for searching for footsteps is in quarries of sandstone, in which the strata are separated by seams of shale. The best indication of their probable occurrence is the rock being "rippled," that is marked with narrow little wavy ridges, such as occur on most sandy shores when the tide is down, and which indicate that the now rocky surface was once either a tidal beach or a shallow surface, over which the ancient animals walked. In the case of fossil footsteps being found, the largest slab which could possibly be removed ought to be brought away, and accurate drawings, or still better, casts, made of several of the footsteps. A plan from accurate measurement ought to be taken of any row of steps. The value of such fossil footsteps would be in a manifold degree increased, if the age of the deposit could be determined by shells found in the same stratum, or above it.

Coal Deposits.—The origin of coal presents a most curious and difficult problem in geology, and though a vast amount of information has been accumulated on the subject, yet good observations in distant countries would be of the highest value. A very brief statement of the most prominent difficulties in the theory of its origin will, perhaps, be the best guide for further inquiries. If we look first to the coal itself, the frequency with which, both in Europe and North America, upright vegetables have been found in and on the coal, and the curious relation between the presence of coal and the nature of the clayey bed (abounding with roots) on which it rests, can leave no doubt that in these so frequent instances the vegetation, whence the coal has been derived, grew on the spot where now embedded. The regularity and wide extent of the beds of coal, and especially of certain subordinate seams in them, the stratification and fineness of the deposits alternating with the coal, and the rarity of channels (such as would have been formed by a stream or river) cutting through the associated strata, all seem pretty clearly to indicate that the coal was not formed on the surface, like a mass of peat, but under water. What, then, was the nature of those vast expanses of shallow water under which the coal was accumulated? The character of the upright fossil plants, according to our present knowledge, absolutely contradicts the idea of their having lived in the sea; yet occasionally strata, containing undoubted marine remains, are associated with the carboniferous series.

On the other hand, how can we believe that lakes, allowing of course their beds slowly to sink, could contain the enormous thickness, amounting in some instances to several thousand yards, of the coal-bearing strata? From these few remarks it will be seen how many points deserve careful examination in any new coal district; the chief points being, the presence of upright vegetables and trunks of trees (of the position of which careful drawings should be made), and whether furnished with roots,—the nature of the beds on which the coal rests, and generally of all the strata; the continuousness and form of the strata, and whether ripple-marked; the existence of marine animal remains, and whether such lived on the spot, or were drifted into their present positions, and many other similar points. It is superfluous to observe that all fossil plants should be collected; those found upright should be carefully distinguished from those embedded horizontally. The contents of any upright stems and of the roots should be examined; as it appears they have generally first become hollow from decay, and then been filled up with mud, which in some instances is charged with seeds and leaves.

Salt Deposits.—Information is much required on this subject; and this is a case in which good suites of specimens, illustrating the nature of the rocks beneath and above the salt, would possess much interest. Do they contain any organic remains? Did such live on the spot where now buried? Do the rocks show signs of having undergone in any degree the action of heat? Are the strata regular, or are they crossed by oblique layers, showing the probable action of currents? Are there ripplemarks, or beds of coarse pebbles, or other indications of the strata having been deposited in shallow water? What is the thickness, form, and dimensions of the beds of salt? Specimens of the salt, and of any associated saline substances, ought to be brought home in bottles for analysis. The origin of beds of salt, found in formations of very different ages in different parts of the world, is at present quite obscure; some authors attribute it to the sinking of superficial sea-water, rendered more saline by evaporation; others to the evaporation of sea-water periodically overflowing extensive low sandy tracts, like parts of the Run of Cutch; others suspect that its deposition is in some unknown way connected with the sea's bottom having been heated by volcanic action. In some countries there are large lakes of brine, often covering thick beds of salt; these deserve examination: on what does such salt or brine rest, whether on the bared underlying strata, or on sand or gravel, such as cover the surrounding country? Does the salt contain the remains of animals or plants? Specimens of the salt ought to be brought home in bottles, and attention paid, whether beneath it there is any thin layer of other saline substances.

Cleavage.—The slaty structure of rocks will at first perplex the young geologist; for in proportion as it becomes well developed, the planes of stratification or of original deposition become obscure, and are often quite obliterated. As the sea-voyager, and especially the surveyor, often visits numerous points on the same line of coast, he possesses some great advantages for studying this subject, and numerous observations made with care would probably give striking results. The range or strike of the cleavage is uniform over surprisingly large areas; whereas both the angle and point of dip varies much; but there is reason to believe that the planes of inclination, examined across a wide tract transversely to the range, will fall into order and show that they are the truncated edges of a few great curves or domes. The relation of the cleavage-planes to those of the stratification, or axes of elevation, should be carefully noted, and likewise to the general outline of the whole country. Long sections at right angles to the strike of the cleavage, with the dip carefully protracted on paper, would be highly interesting. When two chains of hills, each having its independent cleavage, cross each other, careful observations should be made. In all cases, any mineralogical difference, however slight, in the parallel cleavage-layers, deserves attention; but observations on this head would be hardly trustworthy, without the planes of stratification were so distinct that there could be no possibility of confounding (as has often happened) cleavage and stratification. Where a stratum of sandstone, or of any other rock without cleavage, is interstratified with a slaty rock, the surface of junction ought to be minutely examined, to see if the slate has slipped along the planes of cleavage, or whether again the mass has not been either stretched or compressed at right angles to these same planes. Fossil shells have been found by Mr. Sharpe in slaty rocks, which have had their shapes greatly altered, and all in the same direction; here then we have a guide to judge of the amount and direction of the mechanical displacement which the surrounding slate-rocks have undergone.* Observations on cleavage, to be useful, must be numerous and very accurately made.

The foliation of the metamorphic schists, that is, the origin of the layers of quartz, mica, feldspar, and other minerals, of which gneiss, micaceous, chloritic, and hornblendic schists are composed, is intimately connected with the cleavage of homogeneous slaty rocks. Nearly all the proposed observations on cleavage are applicable to foliation. Wherever large districts of foliated and ordinary slaty rocks unite, observations would be most desirable. These foliated rocks have all undergone metamorphic action, that is, they have been mineralogically altered and rendered crystalline by chemical attraction, aided by heat; but this is a most obscure subject, one on which it would appear that much further light will not be thrown without the aid of a profound knowledge of mineralogy or chemistry. It is now known that granitic rocks, which have been fluidified (as may be told by their sending great veins into, and including fragments of, the overlying rocks), are foliated in a more or less perfect degree: in these cases the relation of the planes of foliation with those of the adjoining rocks, which have been metamorphosed but not fluidified, would be eminently curious.

Nature of the Sea-bottom.—As every sedimentary stratum has once existed as the bed of the sea or of a lake, the importance of observations on this head is obvious;

* With respect to further observations on this important point, Mr. Hopkins remarks, in his paper 'On the Internal Pressure of Rock Masses' (Cambridge Philosoph. Transact., vol. viii.), that "the observer should direct his attention especially to those cases in which the inclination of the cleavage planes to the bedding is either small, or nearly 45°."

and no one is so favourably circumstanced for making them as a naval officer on a surveying expedition. The limits of depth under different latitudes at which the various marine animals live or are found strewed dead, is perhaps the most important point for further investigation which can be suggested in the science of geology: scarcely any observations with the dredge have been made within the tropics. Not only the shells, corals, sea-urchins, crabs, &c., brought up from different stated depths, should be preserved, but the proportionate numbers of each kind be carefully noted, as well as the nature of the sea-bottom. An observer could not labour too much in this line, and especially if he would subsequently himself undertake to tabulate and work out the results.*

There is another point of view under which the bed of the sea would amply repay long-continued observations. It is well known that the nature of the bottom often changes very regularly in approaching a coast; the pebbles, for instance, increasing in size in a surprisingly steady ratio with the decreasing depth. But the means by which the pebbles are thus sorted is not known: is it by the oscillation of the waves at ordinary periods, or only during gales; or is it by the action of currents? A chart, with the nature of the bottom carefully noted on it and the currents laid down, would by itself throw some light on this question. The nature of the pebbles being observed, perhaps a point would be found whence they radiated. Excellent observations have been made by engineers on the travelling of shingle beaches, but scarcely anything is

* The best kind of dredge, and the manner of using it, are described under the Zoological Section.

known of their movement under water. In what condition are the pebbles?—are they encrusted (as often happens) with delicate corallines—after a heavy gale are the spines of such corallines found broken? In narrow channels where there are rapid currents, and in the open sea in front of straits, where the water often suddenly deepens, what is the nature of the bottom? To what depth does the sea in a storm render the water muddy? How far from the beach, and to what depth, does the recoil of the waves, or the "undertow," act, for instance, on light anchors? At what depth can the sea wear solid rock? This may sometimes be judged of by the nature of the bottom; thus, where soft mud overlies the rocky surface, we may infer that the sea can hardly now be a destroying agent, even if the inclination of the strata on the adjoining coast shows that rocky strata must once (probably, when the land stood at a different level) have extended much further. Is it at the line of high or low water, or between them, that the breakers most vigorously eat into coast-cliffs? Gigantic fragments of rock, much too large to be themselves rolled about, may be seen at the foot of almost every line of high cliffs; by what means in the course of time will these be removed, as must have happened with their innumerable predecessors? Are they slowly worn away or broken up? It may be well to recollect that in the tropics the powerful action of frost in splitting stones is entirely eliminated. Our observations, moreover, on the alluvial and sub-littoral deposits of these latitudes are not perplexed by the ancient effects of floating ice. The spray of salt-water, above the line of breakers, corrodes by chemical decomposition calcareous rocks; does this play any important part on other rocks? Most bold coasts are fronted by sharp promontories and even isolated pinnacles; are these *exclusively* due to the greater hardness of the rocks composing them, or do not the breakers act more efficiently when eddying round any slight projection?

Rocks rising steeply out of the open ocean, and exposed to the incessant wash of the heaviest surf, are often thickly coated over with various marine animals, and this would seem to indicate that pure water has not the power of gradually wearing away hard rocks, though the waves may occasionally tear off large fragments. Is the washing to and fro of pebbles, or of sand, a necessary element in the corroding power of waves on hard rocks? but how comes it that small land-locked harbours, where the waves can hardly have force to move the shingle, should ever be surrounded by cliffs, which, in most cases, clearly prove that considerable masses of rock have been worn down into mud and removed? Again, at a moderate depth, where the bottom is covered with shingle, does the rolling to and fro of the pebbles wear away solid rock? if so, the pebbles would be clean, and the submarine rocky surface probably worn into furrows or channels at right angles to the beach. Where there are violent currents and eddies, are deep round holes worn in the bottom, like those produced by eddies at the foot of cascades? This, perhaps, might be ascertained by a long pole at the turn of the tide: deep round holes have been observed on rocks formerly covered by the sea, and their origin has perplexed geologists.

Any person steadily attending to these subjects will occasionally be enabled to form an opinion on points at first appearing hopelessly obscure to him. The common deep-sea lead, especially if made a little bell-shaped and well armed, gives a surprisingly good picture of the bottom. There can be no doubt that whoever will for a long period collect and compare observations, made over wide areas and under different circumstances, will arrive at many curious, novel, and important results.

An observer occasionally may arrive at a district where lately some great aqueous catastrophe has occurred, such as the bursting of a lake temporarily formed by a slip, or the rush of a great earthquake-wave over low land. In such cases all the effects produced, such as the thickness and nature of any deposit left—whether stratified irregularly or continuously—whether any rocky surface, over which the debacle has passed, be scored or smooth; all such points should be minutely described, and measurements taken of any great blocks which may have been transported: the great desideratum is accuracy and minuteness.

Ice Action.—The voyager in the Polar Seas would render an excellent service to geology by observing all the effects which icebergs produce in rounding, polishing, scoring, and shattering solid rocks, and likewise in transporting gravel and boulders. Floating ice under two forms is known to transport fragments; namely, coast-ice, in which the stranded boulders are frozen, and icebergs formed by glaciers entering the sea, on the surface of which masses of rock had previously fallen from the surrounding precipices. It is obvious that in the latter case the fragments would generally be quite angular, and they could not be landed in water shallower than the thickness of the submerged ice, requisite to float the berg. On the other hand, the boulders frozen in coast-ice would generally be previously water-worn, and they could be landed on an ordinary beach, and might be driven by the force of the pack high and dry, and perhaps left piled in strange positions. All facts illustrating the difference in the results produced by coast-ice and true icebergs would be very valuable. Do the boulders fixed on coast-ice, when driven over rocky shoals, become themselves scored? Wherever there was reason to believe that a surface had been scored by recent ice-action, a minute description and drawings ought to be made of the depth, length, width, and direction of the grooves; and even large slabs brought home. On true icebergs are the fragments of rock generally fixed or loose; when icebergs turn over, are fragments frequently seen embedded in that part which was under water; and how were they fixed there? The nature, number, size, form, and frequency of occurrence of all fragments of rock seen on floating ice ought to be recorded, and the distance from their probable source. A polar shore, known from upraised organic remains to have been lately elevated, would be eminently instructive. Do great icebergs force up the mud and gravel at the bottom of the sea in ridges like the moraines of glaciers? Can shells, or other marine animals, live in a shallow sea, often ploughed up and rendered turbid by the stranding of icebergs? The dredge alone could answer this. The means to distinguish the effects of ancient floating ice from those produced by ancient glaciers is, at present, a great desideratum in geology. M. Agassiz' work on Glaciers, with its admirable plates, ought to be procured by any one going to the colder regions of the north or south.

Erratic boulders occur in Europe, N. America, and in the southern parts of S. America, which, it is believed by most geologists, were transported by ice; those near mountains, by ancient glaciers; and those on the lowlands, by floating ice. Erratic boulders, when not of gigantic size, may be confounded with rounded stones, transported by occasional great floods or by the coast-action of the surf during slow changes of level of the land. Masses of granite, from often disintegrating into large, apparently water-worn boulders, and then rolling downwards, have several times been erroneously described as belonging to the erratic class. Where the nature of all the rocks in the vicinity is not perfectly known, great size and the angularity of the fragments (though by no means a constant concomitant) are the most obvious distinctive characters; but even when the surrounding country is not at all known, the composition of a single isolated hill or small island may easily be ascertained, and if large fragments of foreign rock lie strewed on its surface, these may be assumed almost certainly to be erratic boulders. Here, however, a caution has been found necessary; for in the case of fragments of *sedimentary* rocks, they may be the last remnant of a denuded overlying formation. Wherever erratic boulders are found, their composition, form—especially attending to whether they are angular, water-worn, or scored, and their size, from actual though rude measurements, should be given.

Both in the north and south a peculiar formation called "till" has been found connected with erratic boulders; it consists generally of mud, containing angular and rounded stones of all sizes up to the largest boulders, mingled in utter confusion, and generally without any stratification. Such deposits should be examined. Sometimes when they are stratified, the upper beds have been found violently contorted, whilst the lower ones are undisturbed, showing that the violence has not proceeded from below, as in ordinary geological cases. Sir C. Lyell has suggested that this effect has been produced by the stranding of great icebergs.

As far as our present knowledge goes, the above enumerated phenomena—such as scored, mamillated, and polished rocks, moraines, erratic boulders, and beds of till, though occurring in latitudes where glaciers do not now occur, where the sea is never frozen, and where icebergs are never drifted, yet have not been observed in either hemisphere higher than about latitude 40°. Hence, on whatever coast ancient ice-action might be discovered, the limit of latitude towards the tropics at which it ceases ought to be carefully investigated. Observations are much wanted on the west coast of N. America and the east coast of Asia; and again in New Zealand and other islands of the Southern Ocean. The period of the ice-action is pretty well ascertained in Europe and North America, and a very great service would be rendered to geology if the same point could be clearly made out in the southern hemisphere; for it might greatly influence our ideas on the climate of the world during the late tertiary periods. Any shells embedded in "till" (though, unfortunately, of very rare occurrence) would decide this point, and it might probably be closely judged of, if till or boulders were found resting on, or covered by, shell deposits.

Distribution of Organic Beings.—As geology includes the history of the organic inhabitants, as well as of the inorganic materials, of the world, facts on distribution come under its scope. Earth has been observed on icebergs in the open ocean; portions of such earth ought to be collected, washed with fresh-water, filtered, gently dried, wrapped up in brown paper, and sent home by the first opportunity to be tried, with due precautions, whether any seeds still alive are included in it. Again, the roots of any tree cast up on an island in the open ocean should be split open, to see if any earth or stones are included (as often happens), and this earth ought to be treated like that from icebergs: it is truly surprising how many seeds are often contained in extremely small portions of earth. Any graminivorous bird, caught far out at sea, ought to have the contents of its intestines dried for the same object. The zoologist who, with a towing-net, fishes for floating minute animals, ought to observe whether seeds are thus taken. These experiments, though troublesome, undoubtedly, would be well worth trying. All facts or traditional statements by the inhabitants of any island or coral-reef, on the first arrival of any bird, reptile, insect, or remarkable plant, ought to be collected. In those rare cases in which showers of fish, reptiles, shells, earth, seeds, confervæ, &c., have fallen from the sky, every fact should be recorded, and specimens collected.

Volcanic Phenomena.—The voyager will probably have ample opportunities of examining volcanic islands, and perhaps volcanoes in eruption. With respect to the latter, he ought to record all that he sees: should the exact position of the orifice be known, he might, perhaps, by observing some point in a cloud, measure with a sextant to what height the fragments were shot forth, and the height of the often flat-topped column of ashes. Having surveying instruments, he ought to map, as carefully as time will permit, any crater remarkable for its size, depth, or peculiar form. M. Élie de Beaumont has found that, owing to the fluidity of lava, streams never consolidate into a thick, moderately-compact mass, except on a surprisingly gentle inclination. On a slope of above 2° or 3°, the stream consists of extremely irregular masses, often forming a hollow vault within. Fresh observations on this point are much wanted in regard to lavas of different composition. The measurements can easily be made by a sextant and artificial horizon.* In

* M. Élie de Beaumont gives the following directions (Mémoires pour servir, &c., tom. iv. p. 173):—

"The method I am in the habit of employing for these kinds of measurements is simple and easy, and a description of it may save useless trouble to others. I place on the edge of the sextant, and behind the fixed mirror, a small piece of white paper, in which there is a narrow opening (ouverture étroite) corresponding to the axis of the telescope. On the exterior surface of the paper a black line is drawn, perpendicular to the plan of the graduated circle, and passing through the centre of the opening above mentioned. A quantity of mercury is poured into a vessel sufficient to form a plane horizontal surface of a certain extent. The telescope of the sextant is then directed vertically over the mercury, and the image of the black line sought for. When this is found, I am certain that the visual ray from the image in the mercury can only deviate from the perpendicular, in so far as the line is not without breadth, and the opening has a sensible size. These two sources of error can be diminished so that the maximum of error shall not exceed a minute. Being once certain of the verticality of the visual ray from the making such observations, comparatively recent streams must be chosen, so that there can be no doubt that the whole consists of a single stream: this cannot be judged of without examining the whole line between the two points of measurement, for some liquid lavas thin out to a very fine edge; and two streams, one over the other, may be thus very easily mistaken for a single one. The composition, thickness, and degree of cellularity of any lava-stream, of which the slope is measured, ought to be described as seen on the sides of fissures, and wherever its internal structure can be made out.

Round many active and extinct volcanoes, both on continents and on islands, there is a circle of mountains, steep on their inner, and gently inclined on their outer flanks. The volcanic strata, of which they are composed, everywhere dip away from the central space, but at a considerably higher angle than it is believed lava can consolidate into such thick and compact masses. These mountains form the so-called "craters of elevation," the origin of which has excited much controversy, and which demand further examination. There is a grand range of mountains of this class at the Mauritius and at St. Jago in the Cape de Verdes, parts only of which have been described. The chief points to attend to are, the *inclination* of the streams by actual measurement, their thickness, compactness, and composition; the form and height of the mountains, whether traversed by very many dikes,

image of the black line, I have only to make the image of any object reflected from the moveable mirror coincide with that of the black line, to have the angle between the vertical, and the line drawn from the centre of the instrument to the object in question, which may be any distant point on the surface of a bed of lava, a glacier, a road, a river, &c."

of which the common direction ought to be recorded; how far the mountains stand apart, and the diameter and outline of the rude circle which they together form. In fact, a most useful service would be rendered by mapping any of these "craters of elevation," or, what would be more feasible, drawing from actual measurements two sections at right angles to each other, across the circle.

Some streams of lava, especially those belonging to the trachytic series (harsh, generally rather pale-coloured lavas, with crystals of glassy feldspar), are laminated. The course of the layers with respect to the course of the stream ought to be minutely studied, both on the surface, at the termination, and flanks of the stream; and, if by a most fortunate chance there should have been formed a transverse section, throughout its entire thickness: this would be a very interesting subject for investigation. A series of specimens ought to be brought away to illustrate the nature of the lamination.

Aerial Dust.—Fine brown-coloured dust has often fallen on vessels far out at sea, more especially in the middle of the Atlantic. This should be collected; the direction and force of the wind (and the course of any upper current, as shown by the movement of the clouds) on the same day, and for some previous days, ought to be recorded, as well as the date, and the position of the ship. Such dust has been shown by Ehrenberg to consist, in many cases, almost entirely of the siliceous envelopes of infusoria. The distance to which real volcanic dust is blown is, likewise, in some respects well worth determining.

Elevation of the Land.—The changes of level, often accompanying earthquakes, will be treated of by Mr. Mallet, but a few remarks on the nature of the evidence to be sought, on changes of level not actually witnessed by man, may be here inserted. Many appearances, such as lines of inland cliffs, of sand-hillocks, eroded rocks, and banks of shingle, often indicate the former effects of the sea on the land when the latter stood at a lower level. But the best evidence, and the only kind by which the period can be ascertained (for the appearances above enumerated, though well preserved, may sometimes be of considerable antiquity), is the presence of upraised recent marine remains. On land which has been elevated within a geologically recent time, sea shells are often found, either embedded in thin layers of sand and mould, or scattered on the bare surface. In these cases, and especially in the latter case, great caution is requisite in testing the evidence; for man, birds, and hermit-crabs often transport, in the course of ages, an extraordinary number of shells. In the case of man, the shells generally occur in heaps, and there is reason to believe that this character is long preserved. To distinguish the shells transported by animals from those uplifted by the movement of the earth, the following characters may be used:—Whether the shells had long lain dead under water, as indicated by barnacles, serpulæ, corallines adhering to their *insides*: whether the shells, either from not being full grown or from their kind, are too small for food; remembering that certain shells, as mussels, may be unintentionally transported by man or other animals in their young state adhering to larger shells; and lastly, whether all the specimens have the same appearance of antiquity. Some shells, which have been exposed for many ages, yet retain their colours in a surprising manner. The very best evidence is afforded by barnacles and boring shells being found attached to or buried in the rock, in the same positions in which they had lived; these may be sometimes found by removing the earth or birds' dung covering points of rock. Where shells are embedded in a superficial layer of soil, though it may appear exactly like vegetable mould, specimens of it should be preserved, for the microscope will sometimes reveal minute fragments of marine animals. In all these cases, specimens of the shells, though broken and weathered, and having a wretched appearance, must carefully be preserved; for a mere statement that such upraised shells resembled those still living on the beach is absolutely of no value. It should be noticed whether the proportional numbers between the different kinds appear to be nearly the same in the upraised shells and in those now cast on the beach. The height at which the marine remains occur above the level of the sea should be measured. In confined situations where the change of level appears to have been small, much caution must be exercised in receiving any evidence; as a change in the direction of the currents (resulting from alterations in neighbouring submarine banks) may cause the tide to flow to a somewhat less height, and thus give the appearance of the land having been upraised.

Wherever a tract of country can be proved to have been recently elevated, its surface, as exhibiting the late action of the sea, is a fertile field for observation. On such coasts, terraces rising like steps, one above another, often occur. Their outline and composition should be studied, diagrams made of them, and their height measured at many and distant parts of the coast. There is reason to believe that in some instances such terraces range for surprisingly long distances at the same height. Where several occur on opposite sides of a valley a spirit level is almost indispensable, in order to recognize the corresponding stages. Where ranges of cliffs exist, the marks of the erosion of the waves may sometimes be expected to occur, and as these generally present a defined line, it is particularly desirable that their horizontality should be ascertained by good levelling instruments, and if not horizontal, that their inclination should be measured. Where more than one zone of erosion can be detected all should be levelled, for it does not necessarily follow that the several lines are parallel. Along extensive coasts, and round islands which have been uplifted to a considerable height, and where we now walk over what was, within a late geological period, the bed of the sea, it would be well to observe whether extensive sedimentary deposits have been upraised; for it has often been tacitly assumed that sedimentary deposits are in process of formation on all coasts.

Subsidence of the Land.—This movement is more difficult to detect than elevation, for it tends to hide under water the surface thus affected. Evidence, therefore, of subsidence is very valuable; and this movement, moreover, has probably played a more important part in the history of the world than elevation, for there is reason to believe that most great formations have been accumulated whilst the bed of the sea was sinking. Subsidence may sometimes be inferred from the form of the coast-land;

for instance, where a line of cliffs, too irregular to have been formed by elevation alone, plunges precipitously into a sea so profoundly deep that it cannot be supposed that the now deeply submerged portions of the cliff have been simply worn away by the currents. The direct evidence of subsidence, if not witnessed by man, is almost confined to the presence of stumps of trees, peat-beds, and ruins of ancient buildings, partly submerged on tidal beaches. Ancient buildings may sometimes afford such evidence in unlikely situations: it has been asserted, that in one of the volcanic islands in the Caroline archipelago there are ruins with the steps covered by the sea. Again, at Terceira, at the Azores, there is an old church or monastery said to be similarly circumstanced.

*Coral Reefs.**—The most important point with respect to coral reefs, which can be investigated, is, the depth at which the bottom of the sea, *outside the reef*, ceases to be covered with a continuous bed of living corals. This can be ascertained by repeated soundings with a heavy and very broad bell-shaped lead, armed with tallow, which will break off minute portions of the corals or take an exact impression of them: it can thus also instantly be seen how soon the bottom becomes covered with sand. This limit of depth ought to be ascertained in different seas, under different latitudes, and under different exposures. For collecting specimens of the corals, it is to be feared that the dredge would become entangled, but chains and hooks may be lowered for this purpose. There is reason to suspect that different species of corals

* The only work specially written on this subject is 'The Structure and Distribution of Coral Reefs,' by Mr. Darwin.

grow in different zones of depth; so that in collecting specimens, the depth at which each kind is found, and at which it is most abundant, should be carefully noted. It ought always to be recorded whether the specimen came from the tranquil waters of a lagoon or protected channel, or from the exposed outside of the reef. The small reefs within the lagoons of certain atolls (or lagoon-islands) in the Indian Ocean all rise to the surface; whereas in other atolls not a single reef rises within several fathoms of the same level. It would be a curious point to ascertain whether the corals in these cases consisted of the same species; and if so, on what possible circumstance this singular difference in the amount of their upward growth has depended.

Any facts which can elucidate the rate at which corals can grow under favourable circumstances, will ever be interesting: nor should negative facts, showing that within a given period reefs have not increased either laterally or vertically upwards, be neglected. In a full-grown forest, to judge of its rate of growth, a part must be first cut down; so is it probably with reefs of corals. The aborigines of some of the many coral islands in the great oceans might perhaps adduce positive facts on this head; for instance, the date might be known when a channel had been cut to float out a large canoe, and which had since grown up.

For the classification of coral reefs, the most important point to be attended to, is the inclination of the bed of the adjoining sea; and secondly, the depth of the interior lagoon in the case of atolls, and of the channel between the land and the reef, in Encircling or Barrier, and in

Fringing reefs. Whenever it is practicable, soundings ought to be taken at short ascertained distances, from *close* to the breakers in a straight line out to sea, so that a sectional outline might be protracted on paper. In those cases in which the bottom descends by a set of ledges or steps, their form ought to be particularly attended to; and whether they are covered with sand or by dead or living coral; and whether the corals differ on the different ledges: the same points should be attended to within the lagoon, wherever its bed or shore is step-formed: the origin of these steps or ledges is at present obscure. In the Indian and Pacific oceans there are entire reefs, having the outline of atolls or lagoon-islands lying several fathoms submerged; there are likewise defined portions of reefs both in atolls and in encircling reefs similarly submerged. It would be particularly desirable to ascertain what is the nature of these submerged surfaces, whether formed of sand or rock or living or dead corals. In some cases two or more atolls are united by a linear reef; the form of the bottom on each side of this connecting line ought to be examined. Where two atolls or reef-encircled islands stand very near each other, the depth between them might be attempted by deep soundings: the bottom has been struck between some of the Maldiva atolls. Generally the form and nature of the reefs encircling islands ought to be compared in every respect with the annular reefs forming atolls.

On the shores of every kind of reef, especially of atolls and of land encircled by barrier reefs, evidence of the slow sinking of the land should be particularly sought for;

for instance, by stumps of trees, the foundation-posts of sheds, by wells or graves or other works of art, now standing beneath the level of high-water mark, and which there was good reason to believe must have once stood above its level. The observer must bear in mind that cocoa-nut trees and mangroves will grow in salt-water. If such evidence be found, inquiry ought to be made whether earthquakes have been felt. On the other hand, all masses of coral standing so much above the level of the sea that they could not have been thrown up by the breakers during gales of wind, at a period when the reef had not grown so far out seaward, should be investigated and their height measured. There is reason to believe that some coral-reefs have been thought to have been upraised, owing to the effect of the lateral or horizontal extension of the reefs having been overlooked; for the necessary result of this outward growth is gradually to break the force of the waves, so that the rocks, now further removed from the outer breakers, become worn to a less height than formerly, and the more inland corals not being any longer constantly washed by the surf, cease to live at a level at which they once flourished. It is indispensable that specimens of all upraised corals, and especially of the shells generally associated with them, should be collected; for there can be no doubt that ancient strata containing corals, have in some instances been confounded with recent coral-rock. The importance of ascertaining whether coral-reefs have undergone, or are undergoing, any change of level, depends on the belief that all the characteristic differences between Atolls and Encircling reefs on the one hand, and

Fringing reefs on the other, depend on the effect produced on the upwardly-growing corals by the slow sinking or rising of their foundations.

A thick and widely-extended mass of upraised recent coral-rock has never yet been accurately examined, and a careful description of such a mass—especially if the area included a central depression, showing that it originally existed as an atoll—is a great desideratum. Of what nature is the coral-rock; is it regularly stratified or crossed by oblique layers; does it consist of consolidated fine detritus or of coarse fragments, or is it formed of upright corals embedded as they grew? Are many shells or the bones of fish and turtle included in the mass, and are the boring kinds still in their proper positions? The thickness of the entire mass and of the principal strata should be measured, and a large suite of specimens collected.

In conclusion, it may be re-urged that the young geologist must bear in mind, that to collect specimens is the least part of his labour. If he collect fossils, he cannot go wrong; if he be so fortunate as to find the bones of any of the higher animals, he will, in all probability, make an important discovery. Let him, however, remember that he will add greatly to the value of his fossils by labelling every single specimen, by never mingling those from two formations, and by describing the succession of the strata whence they are disinterred. But let his aim be higher: by making sectional diagrams as accurately as possible of every district which he visits (nor let him suppose that accuracy is a quality to be acquired at will), by collecting for his own use, and carefully examining numerous rock-specimens, and by acquiring the habit of patiently seeking the cause of everything which meets his eye, and by comparing it with all that he has himself seen or read of, he will, even if without any previous knowledge, in a short time infallibly become a good geologist, and as certainly will he enjoy the high satisfaction of contributing to the perfection of the history of this wonderful world.