THE STRUCTURE OF THE EARTH

T·G·BONNEY, ScD., F·R·S

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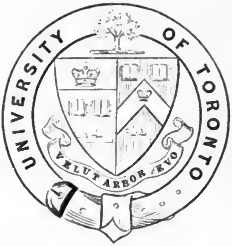

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THE STRUCTURE OF THE EARTH

CHAPTER I

THE PROBLEMS AND METHODS OF GEOLOGY

GEOLOGY may be defined as the endeavour to answer the question, What is the past history of the planet on which we are living? As a science it is the outcome of reasoning inductively from observations. To a certain, but only a limited, extent, its conclusions can be verified by experiment, so that, as a rule, its hypotheses must be tested by ascertaining whether they accord with facts, and especially those gathered by extending the field of observation. Many of the mistakes which have been made in the past, some perhaps which are even now current, are the result of generalisation from insufficient knowledge. Hypotheses founded on experience restricted to one's own back garden are as mischievous in science as they are in politics. As the late Sir Charles Lyell rightly said, travel is the first and the second and the third thing necessary in the education of a geologist, provided he starts with knowledge sufficient to enable him to understand what he sees. Hasty generalisations, no less than efforts to force the results of observation into harmony with preconceived hypotheses, were for long baneful to the science. It is the duty of all who desire to be its students to be ever on the watch, endeavouring to observe accurately and to reason soundly, to ascertain new facts and apply them to test accepted conclusions.

One or two simple examples may serve to show the nature of geological problems, and how they present themselves to anyone who goes about the world with his eyes open. Some coasts are rock-bound, the waves even at low tide breaking against rugged cliffs, but on others we can walk then—and sometimes even at high water—on low banks of shingle or stretches of sand. Whence have these come? What has shaped the pebbles of the one or gathered the grains of the other? But we can find pebbles and sand, not only on the sea-shore but also in the beds of rivers, especially when their streams are generally strong. Here the same question is presented in a slightly different form; and if we are not content to answer it by saying that the gravel, sand, or mud were created as they now are, they must have a history. What that has been it is our business to ascertain.

Again, the surface of the ground is seldom a dead-level like a billiard table. Here it is gently undulating; there it forms distinct hills. These are often separated by valleys, which as a rule broaden and diminish in slope as we pass outward from the higher land. If, however, as is usual, we approach this in the opposite direction, we commonly find that the outlines of the scenery become bolder. The hills are more rugged in aspect; their slopes are interrupted by crags; the valleys are sometimes bordered by cliffs, and we begin to notice a connection between the nature of the rocks and the forms which they assume. In another place we may be travelling towards a mountain range. It rises against the sky with a sharp and serrate crest, which becomes yet grander as we approach. We enter it to find scenery on a larger and more impressive scale than in any lowland hills: glens and gorges, torrents and waterfalls, shattered ridges and towering peaks. What is the reason, the explanation, of these? Have the undulating uplands and rounded downs of Kent and Sussex, the dales and craggy hills of Derbyshire, the peaks and tarns of North Wales, been as we now see them since the beginning of the seventh day of Creation, or have they been shaped in the course of countless ages by the slow but unceasing action of natural forces ? These instances may serve as examples of one large group of questions—those connected with the physical history of the earth.

But there is another group which presents itself in many places. Let us take one of the most striking instances, and transfer ourselves in imagination to Alum Bay in the Isle of Wight. Those singular vertical layers of diverse-coloured sands call for an explanation, but let us pass them by for the moment and mount the rough slopes of Headon Hill on the northern side. Very soon we find ourselves treading upon shells, in some respects resembling, in others differing from, those now to be found in our own or in other countries. Their condition and aspect suggests that they have been long dead : they do not correspond in form with those which we know to be still living. When first we find them they may be lying loose on the surface, but a little search, as we mount upwards, shows that they were once embedded in the successive beds of marl or soft limestone, over which we pass in mounting upwards. In one place we find some that so closely resemble those now living in seas that we feel sure they must have had their home in salt water ; yet, as their burial-ground is far above the reach of the waves in even the wildest storms, they must have lived and died where they are found. In another place the shells resemble those still living in streams or lakes, and by degrees we begin to perceive that the remains found in the different beds suggest alternations of fresh-water, or estuarine, or marine conditions. Other places present similar problems, though in diverse forms, and when we have succeeded in solving them we find that we have deciphered a few pages of the earth's history, and begin to wonder whether it contains many chapters, perchance even volumes.

Perhaps it was such an occurrence as this of the relics of a dead past which first set men to consider what could be their meaning. Certain it is that the question was asked—probably not for the first time—

more than five-and-twenty centuries ago. In fact thoughtful men, even if they lived in districts where fossils are not found, could hardly have avoided asking themselves the question whether the earth had a beginning, and if so, how it began ? Such questions in regard to the origin of things generally form a part of Oriental systems of philosophy and may go back to a remote antiquity, but, even if they were at first suggested by observation, the treatment of them and its results have been metaphysical rather than scientific. But the more practical West took a better course. We find the results of induction from observation clearly stated in the writings of Ovid, who professes, probably with good reason, to represent the opinions of Pythagoras,[1] who, so far as we know, was one of the first in Europe to make inductive reasoning a part of his philosophy. He taught his disciples that land had been converted into sea, and sea had overwhelmed the land, that valleys had been excavated by running water, rivers had altered their channels, plains been upheaved into hills, volcanoes broken out, and other important changes made in the surface of the earth. In fact, during the great days of Rome, a fair amount of real knowledge had been acquired in regard to geology, though it was mingled with many quaint and erroneous notions. But culture and learning were submerged at the fall of the Empire by the invading flood of ignorance and barbarism, and the ultimate triumph of Christianity unfortunately restricted that liberty of investigation which paganism had permitted. Though the advocates of the former had little love for the Jew, they believed his scriptures to be conclusive in matters of cosmogony ; thus to dispute the literal accuracy of the statements in Genesis was to incur the censure of the Church, and that, from the seventh to the fifteenth century, was no trifling matter. On this subject the Protestant held opinions more definite than the Roman Catholic, and the former, though less able to do bodily harm to the supposed heretic, was ready

[1] Pythagoras, *cir.* 540–510 B.C. ; Ovid, 43 B.C.–A.D. 18.

to inflict all penalties in his power, or at any rate was hardly less hostile in spirit to an interference with traditional opinions. Geologists, even in the earlier part of the last century, were often vehemently denounced from platform and pulpit, and in its sixth and seventh decades "the drum ecclesiastic" was beaten, probably for the last time, vigorously, but in vain against evolution.

When the path of induction entailed discredit, if not danger, a desire to escape from its conclusions tempted geologists, though perhaps unconsciously, to seek refuge in hypotheses more or less fantastic. One of these cut the Gordian knot by affirming that fossils were not the relics of creatures which once had lived, but were "sports of nature"—mere imitative forms, like the supposed moss in agate or a portrait in a piece of jasper. Some persons—but perhaps it would be unjust to number them among geologists—even went so far as to declare that fossils were traps, set by the Almighty to ensnare presumptuous and over-curious inquirers into the earth's past history. Others considered them to be proof that nature had been trying her prentice hand in making models of creatures, which were presently to be animated with life, before undertaking the more serious work, an idea which was not without its sturdy advocates, even when the Royal Society was founded in the days of Charles II.

Others found a way out of the difficulty by regarding all fossils as relics of the Noachian deluge. Indeed, at one time they were considered to be such strong proof of the accuracy of the book Genesis that Voltaire attempted to discredit their evidence by suggesting that sea-shells which had been discovered, especially in the Alps, had been accidentally lost by pilgrims to certain shrines, who had brought them from these places as sacred souvenirs. That idea was of course too absurd to win many disciples, but the appeal to the Noachian deluge found some favour little more than a century ago, and though a modification of this idea has been since then occasionally advocated as an explanation of particular phenomena, it would now be unanimously discarded as accounting for the general distribution of fossils.

Further study shows that these (we will speak for the moment of molluscs only) differ not only in their shapes, but also in their states and modes of preservation. Some of those from Headon Hill remind us of species, which, as we can learn from collections in any good museum, have inhabited rivers or lakes ; others embedded in the sandy clays which are disclosed at low tides in Bracklesham Bay are like those which now live in salt water, and a closer study shows us that they resemble those now found, not in British but in tropical seas. The shells also from the latter place are, as a rule, more friable than those from the former, having lost a larger proportion of their organic cement. Both differences, but especially the former, suggest that the Bracklesham molluscs lived at an earlier date in the world's history. Again, if we examine the chalk which forms hill ranges in the Isle of Wight and in Sussex, we find that it contains shells still more different, both in kind and in mineral condition, from those now in existence. Not a few of them belong to genera which do not now live in any part of the globe, and in most of them the calcareous material of the shell has not onlyparted with its organic constituent, but also assumed a crystalline condition. In short, we find, as we pursue our researches, that the divergence of form and structure from still living organisms becomes, as a rule, yet more marked as we extend our observation to greater depths from the surface, and that these dead and gone organisms in some cases, instead of being converted into crystalline calcite, exist only as casts in the hardened rock, or have been replaced by some mineral different from the original one.

Further examination shows, as we shall presently see, that the more widely the fossils embedded in a rock depart from remains of creatures which are still living, the more ancient that rock will be, and that a study of the life history of the earth discloses a progress and suggests that this is by an evolution, more or less gradual, rather than by new creations after occasional destructions.

These instances may suffice to indicate the nature of the problems presented to the geologist. Both they, and the methods adopted in solving them, bear some resemblance to those employed in recovering the history of a nation whose annals, language, and even its alphabet have been forgotten. The investigator looks below the surface of the ground, lays bare the sites of buried cities, observes the sequence of their ruined foundations and of other relics, collects every fragment of an inscription, and then sets to work by patient research and repeated comparison of symbol with symbol, of group with group, by investigations in languages probably germane to that which has been lost, to recover its alphabet, its words with their significance and connection, and at last, as has been done with the hieroglyphs of Egypt and the cuneiform characters of Assyria, to reconstruct a history and bring into life a long-forgotten past. In geology, no less than in archæology, there are problems still awaiting solution, but in the one science no less than in the other we are justified in asserting that we have obtained a fairly accurate idea of what has happened in the history both of an ancient people and of the earth itself, though the latter has extended over millions of years, and only its final paragraphs could have been recorded by man.

CHAPTER II

THE EARTH'S CONSTITUTION AND AGE

THE earth's shape is very nearly a spheroid, the polar diameter of which is 7899·1 miles and the equatorial 7925·6. As the difference between these is 26·5 miles, the maximum thickness of the equatorial protuberance, as its gradual departure from a truly spherical form is often called, amounts to rather more than 13 miles. Strictly speaking, as we shall presently see, this statement is not quite accurate, but it is sufficiently so for ordinary purposes. The earth, then, may be defined as a huge ball, partially covered by water (lakes, seas, and oceans), and wholly enveloped in an atmosphere that may extend, though in a very attenuated state, to something like 500 miles above it. The earth's surface is far from even, though in some parts which are called plains it is almost level; other parts, which are at a greater elevation above the sea, and are more or less worn into valleys, are called plateaux, while others are diversified by hills or wrinkled into mountains. To these reference will be made in later chapters; at present it will suffice to say that the highest summit among the last-named (Mount Everest) is just over 29,000 feet, several other peaks ranging between that and 20,000 feet. If all the seas and oceans were dried up, the part of the crust thus disclosed would exhibit irregularities somewhat different in form and on a rather larger scale, for the submarine contours are less sharply accentuated than those above water. It has often been said that, so far as the gradients go, it would be possible to drive from Valentia to Newfoundland without putting on the drag, except perhaps off the Irish coast. In fact, if a cast were made of the part of the crust now beneath the several oceans, it would present us, when laid open to view, with a series of gently shelving plains and vast plateaux, hardly anywhere assuming a mountainous aspect, though the maximum elevation would exceed that of any point on the present land by about 1900 feet.[1] The average depth of the ocean is about 2½ miles more than the average height of the continental land above it, and the

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[1] The deepest sounding yet obtained is 5155 fathoms (to the east of the Kermadec Islands) in the South-West Pacific, and several soundings in that ocean range between 4000 and 5000 fathoms. The greatest depth obtained in the Atlantic (to the north of the West Indies) is 4660 fathoms, the largest part of that ocean being not so much as 3000 fathoms, while the Indian Ocean nowhere reaches 3300 fathoms (H. R. Mill, *International Geography*, ch. vi.).

ratio of the surface of the one to that of the other is about 72 to 28. It has also been remarked that if London be taken as the centre of a hemisphere, this contains far the largest portion of the land surface of the globe—the whole of Europe and North America, nearly all Asia and the greater part of South America; the remainder of the last, the Antarctic land, and Australia being the only areas of importance in the other one. This unequal distribution of land and water can hardly be fortuitous, and we may refer to it again. One or two other peculiarities of grouping have also been noticed, which, if only accidental coincidences, are certainly peculiar; such as the grouping of the continental and insular shores of the Arctic Ocean, which seem to lie along a circular curve inclined, in the direction of Behring Strait, at about 5° to one of latitude. Again, a similar curve, inclined at about 10° in the direction of Paris, would pass through the greater part of the inland seas or great lakes of the Old and New Worlds. Another circle, the normal to which makes an angle of nearly 20° with the polar axis, passes through the Isthmus of Panama (the lowest point in the watershed of the two Americas) and crosses almost all the great deserts of the Old World.[1]

The globe revolves once in 23 hours 56 minutes about its shorter axis. This statement is not quite accurate, for its axis of rotation varies slightly in position from time to time; but the deviation is not cumulative, and is so slight that we cannot regard it as even sufficiently important to make any sensible alteration in the climate of this or that place. The earth also revolves in an ellipse about the sun, which is situated in one of the foci, and the plane of this is inclined at an angle of nearly 23½° to the equatorial plane of the other. This inclination causes the changes in the length of the day, in climate, and in other matters, for which we must refer our readers to some treatise on astronomy.

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[1] E. Reclus, *The Earth* (translated by H. Woodward), Part II. ch. vii.

The mean distance of the earth from the sun is about 92,800,000 miles; the minimum distance being 91,100,000 miles and the maximum 94,600,000 miles. It is so difficult to grasp the significance of such vast figures that we may venture on a rough illustration, in the hope of giving some idea of the relative distances and sizes of the different members of the solar system. Suppose the sun to be represented by a globe two feet in diameter and the orbits of the planets by circles, Mercury would be a grain of mustard seed and the radius of its circle 82 feet; Venus a pea, with a radius of 142 feet; the Earth another pea, its circle having a radius of 215 feet; Mars a very small pea, with a radius of 327 feet. The asteroids may be omitted, for none of them would be bigger than a grain of sand. Jupiter would be a moderate-sized orange, Saturn a small one, Uranus a big cherry or a small plum, and Neptune about the same size; while the radius of their several circles would be a quarter of a mile, two-fifths of a mile, three-quarters of a mile, and a mile and a quarter. In the case of the sun we can form some idea of the greatness of its distance from the earth by remembering that light takes 8 minutes and 16 seconds to come from it to us,[1] and that if a heat-proof baby were born there and its first squall could be transmitted to us by some multiple megaphone, it would be fifteen years old before that sound reached our ears.

We must abstain from discussing a question so difficult and controversial as the origin of our planetary system, and take up the history of the earth at the stage (about which there is less difference of opinion) when it had become a glowing mass, possibly molten at the surface, but perhaps solid in the interior. Liquid rock would then serve for its ocean, for the present one obviously could only exist in the state of vapour, and would thus form part of the atmosphere. One consequence of this is important, as we shall presently see; namely, that the pressure upon every square inch of the

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[1] The velocity of light is about 186,000 miles a second; that of sound about 1100 feet in the same time.

earth's surface, instead of being 14 pounds, would be about 310 times as great. Gradually as this surface cooled by radiation, a crust would form upon it, at first neither uniformly nor simultaneously. This, for some time, would keep breaking up, and would very probably sink in the underlying "sea of fire," but such disruptions would gradually become rarer until that sea was permanently frozen over. After this the huge ball would continue to cool and its crust to thicken. At last its surface would cease to glow, and water, precipitated in copious showers from the steamy atmosphere, would begin to rest upon it. Rivers and seas would now commence the work which will presently be described, and as time went on life would become possible for something more than the fabled salamander. Thus the sun, the earth, and the moon represent three stages in the history of a celestial system. The first, so far as we can ascertain, consists of an intensely heated atmosphere of a complex character, in which most, if not all, of the known constituents of this earth are present in the state of vapour, and which envelops a great globe, perhaps solid, less luminous, but also at a very high temperature. The state of the second planet we may suppose to be generally known; the third, usually regarded as the offspring of the earth's hot youth, is now waterless and rigid, probably without any internal heat, but alternately scorched by the untempered rays of the sun and exposed to the cold of space.[1]

Apart from other considerations, actual experiment justifies the inference that the interior of the earth is still at a high temperature. That of the surface and of the adjacent atmosphere fluctuate simultaneously, so that they show not only a rise to a maximum during the summer and a fall to a minimum in the winter, but also similar oscillations between day and night and considerable variations from one day to another. If

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[1] As the moon turns upon its axis in the same time that it revolves about the earth, the lunar day is almost a fortnight long. Its volume is about one-fiftieth that of the earth, and its distance (from the centre) 238,833 miles.

the observations be plotted down as curves, say, continuously during each day and for each day in the year, we shall find that the curves of the former, if taken just above and just below the ground, present no sensible difference, but that their diurnal irregularities disappear as we descend, and the recording curve assumes the form of one which in the course of a year rises to a maximum and sinks to a minimum. This will occur at a depth of about a yard, after which this curve also will exhibit a similar flattening-out, till at a depth of about sixty feet the effect of surface changes is no longer perceived, and the thermometer remains steady. But after this, if observations be taken at increasing depths, the temperature is found to rise. The rate of this is not the same at all places, or strictly proportionate to the vertical distances between the points of observation. Evidently it depends to some extent upon the nature of the rock penetrated and other local circumstances; but in 1882 a committee of the British Association, after studying all the observations then available, came to the conclusion that a rise of 1° F. for each 64 feet of descent was, under ordinary circumstances, a fairly accurate estimate.[1] For a rough calculation, however, we may take 1° for 60 feet. With this rate the temperature at a depth of 6000 feet (rather more than a mile) below London would be about 150° F., and we should read 212° (that at which water boils on the surface) at a little less than 10,000 feet. Lead would melt (taking no account of the effect of pressure) at about 35,000 feet, or rather less than seven miles, while at a depth of from 25 to 30 miles almost all the materials of which the earth's crust is composed would

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[1] The local variations are considerable. Taking depths of at least 1000 feet, a rise of 1° F. was observed for 57 feet in a boring at Grenelle near Paris, and for 55 feet at Kentish Town, London. The Sperenberg boring to a depth of 4712 feet, almost wholly in rock-salt, gave 1° in 51½ feet, while the Scarle boring (Lincolnshire) gave 69 feet, and a coal-pit at Dukinfield 72 feet. A Bohemian mine gave 1° in 126 feet, and Bootle waterworks (1392 feet) 1° in 130 feet. The slowest increase on record, so far as I know, was in a mine near Lake Superior, which gave 1° for 223·7 feet.

be at a temperature which, on its surface, would suffice to melt them.

But they may be kept solid, at any rate for a still further distance, by the tremendous pressure which they suffer from the weight of the overlying material, so that both the thickness of the solid crust and the condition of the earth's interior are questions to which we cannot at present give a definite answer. Three opinions have been maintained: that our globe consists of a solid shell, not many miles in thickness, enclosing a liquid interior; that it is solid to the centre; and that a solid shell is separated from a solid core by a liquid layer. Mathematicians, reasoning from the phenomena of the tides and the precession of the equinoxes, have inferred that the earth must either be defended by a very thick shell or be solid throughout, perhaps with the exception of some great reservoirs of molten matter. For instance, it was maintained by W. Hopkins that the solid shell could not be less than 800 miles thick (about one-fifth of the radius), and by Lord Kelvin that the effective rigidity of the globe as a whole could hardly be inferior to that of a ball of steel of the same size, in which case the minimum thickness necessary would be at least half its radius, and it might well be solid throughout. Delaunay and Henessy, however, questioned the validity of these conclusions, and argued in favour of a solid crust considerably less than 100 miles in thickness. This diversity of opinions, even among skilled mathematicians, is not really surprising, because in order to obtain numerical results assumptions have to be made in regard to the conductivity of rocks, the effect of pressure on their melting-point, the increase of temperature with depth,[1] the critical-points of their materials,[2] and the like, which

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[1] It is generally admitted that the temperature does not increase at a uniform rate in descending. Lord Kelvin supposed that at about 80 miles it would become 1° F. for 141 feet; at 160 miles, 1° for 2550 feet, or that the temperature at the centre would be from 6000° to 7000°.

[2] The critical temperature is that beyond which no pressure can keep a substance liquid. For water this is 689° F.

often cannot be precisely determined; so that, however impregnable the mathematical reasoning may be, those results may be far from accurate.

During the last few years, Arrhenius, an eminent Scandinavian chemist, has put forward a view which is worthy of careful consideration, since it seems to explain some of the difficulties which have arisen from the study of volcanoes and earthquakes. In his opinion water makes its way by capillarity through the sea-floor towards the increasingly heated interior of the earth. At a depth approaching eight miles it would reach a zone where the temperature was higher than 689° F., the critical-point of water, which beyond this must be in a gaseous condition, and rather before reaching this temperature it begins to surpass silicic acid in its power of combining with the bases, which are commonly associated with this acid, in the earth's magma. It accordingly decomposes them, setting the other free. But when any kind of pressure squeezes up the softened magma into pipes or fissures, this becomes cooled and the silica displaces the water, which produces explosions.

He also argues that, as recent physical investigations have shown, the rule which holds with water in regard to its critical-point probably applies to all known substances. It therefore follows that, at great depths, the constituents of the globe must really be in the gaseous state, since they are at a temperature which defies the power of pressure to keep them solid or even liquid. Hence he concludes that (1) the melting-point of most rocks would be reached at a depth of about 25 miles. At a considerably greater depth the critical-point is passed and the magma is in a gaseous state. Its condition, however, under the great pressure is altogether different from that of a gas as we know it, for it is intensely rigid.[1] Probably this large inner nucleus consists of some metallic substance, for the specific gravity of the earth as a whole is about 5·5 times that of water, while most of the rocks which form

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[1] The molecules of the gas are very closely packed by the pressure, but are nevertheless too hot to stick together.

its crust (excluding the ordinary metals) are from about 2·5 to 3·5 as heavy as water.[1] Be this as it may, recent investigations in more than one direction suggest the existence, at a depth of from 20 to 30 miles from the surface, of a zone the materials of which are in a very different condition from that of the overlying crust or of the interior mass.

We pass on to touch briefly on another very vexed question—the figure of the earth. The singular grouping of the larger areas of land and water has been already mentioned; the general tendency of the continental masses either actually to taper to the south or to throw out promontories in that direction is another suggestive fact, so that, though we may be content for general purposes to regard the earth as a spheroid of revolution, we are prepared to find that the statement needs some corrections not altogether unimportant. In 1878 Colonel Clarke, after a very thorough discussion of all data then available, came to the conclusion that the earth's form, instead of being a true spheroid, was an ellipsoid, in which one of the equatorial diameters was slightly longer than the other. But five years earlier Mr. Lowthian Green,[2] from more general considerations, had maintained the earth to have more resemblance to a tetrahedron,[3] the edges of which determined the general position of the continents, and the faces those of the great oceans. At a later date than both, Mr. Jeans suggested that the figure was pear-shaped rather than tetrahedral. If it imitated a stout example of that fruit, the preponderance of land in a more northern hemisphere and of ocean in the other one would be explained, and the Antarctic land-mass would represent the stalk-end of the pear. We should anticipate a considerable departure from the strict outline of a geometrical figure if we suppose the moon, in accordance with the view of Sir G. H. Darwin

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[1] For a fuller account see R. H. Rastall, *Geol. Mag.*, 1907, p. 173.

[2] *Vestiges of a Molten Globe*, 1873.

[3] A regular figure with four faces, each of which is an equilateral triangle.

and other eminent mathematicians, to have been flung off from the earth while the latter was in process of consolidation. The pear-shaped form, according to Mr. Jeans, was due to an effort on the part of the earth to dismiss a second satellite, which the increasing consolidation prevented it from doing. With some modification, these views are to a considerable extent both reconcilable and accordant with the facts; but it is impossible to pursue further a subject which, like the condition of the earth's interior, can only be adequately discussed by masters in mathematical physics.

Yet one more subject, no less difficult, demands a brief mention—the age of the earth. When geologists escaped from the shackles of the Mosaic cosmogony and the Ussherian chronology, Hutton's dictum—that the earth indicated to him neither signs of a beginning nor symptoms of an end—gained more adherents; and about three-quarters of a century ago the Uniformitarian school, of which Sir Charles Lyell may be regarded as the prophet, began to command a majority among geologists, and its disciples showed a speculative disposition, as if they had an unlimited credit at the bank of time. Protests, however, began to be raised, more especially by students of physics, and about 1867 Professor William Thomson (afterwards Lord Kelvin) declared that the earth's history must be compressed into 100,000,000 years, because the laws of cooling and conductivity, the increase of internal heat and the phenomena of the tides, indicated that, assuming the earth to have been once molten and to have begun to solidify on reaching a temperature of 7000° F. (a rather liberal allowance), this could not have happened much more than 98,000,000 years ago. At a later date, with a more intimate knowledge of solar physics, he greatly reduced this period, maintaining that the sun can hardly have given out light and heat for more than about 20,000,000 of years. But in the former case, as many geologists protested, and still more in the latter, the results, though the general arguments might be incontestible, involved several elements of uncertainty, while still more recently the discovery of radio-active elements has introduced a new factor which cannot but modify the above-mentioned conclusions. At the present moment there is perhaps some tendency to relapse into spendthrift habits in the matter of time; but if we bear in mind how much has still to be learnt about radio-active substances, and those other difficulties which have been already mentioned, it will be wiser to suspend judgment, and be content to affirm that though the age of the earth is to be measured by millions of years, it must be very far from so boundless as the earlier Uniformitarians supposed.

Of late years attempts have been made to test these estimates of the mathematician and approximate to the earth's age by evidence more directly geological. Much of its crust is formed, as we shall presently show, of materials most of which have been deposited by water. These—the stratified rocks—have been classified, and attempts have been made to estimate the average thickness of their several members and the time which each would require for its deposition. Both these involve, as we can well imagine, great difficulties, and only the roughest estimates are possible of either, for as we shall presently see, when materials derived from the land are deposited in the sea they generally assume a wedge-like shape, because the coarser are the first to come to rest. Again, the record is often not continuous. Nature's work is destructive as well as constructive, and hundreds of feet of rock may have been removed and again incorporated with some deposit at quite another place and of a much later date. Hence the estimates vary considerably, and besides this some of the most ancient members of the stratified group present difficulties of their own. Putting these aside for the moment, and beginning with the earliest deposit, which presents more than mere traces of organic life, the several "stone books," the volumes in which the earth's history is written, are supposed to have a total thickness of thirty-four miles, and those earlier tomes in which all but the latest pages are wholly blank may be not much less than sixteen miles. We know no reason why life should not have been possible on the earth during most of this latter period, and the remains of it at the base of the other and larger one show, from their variety and their position in the ascending scale of organic life, that it must have begun at a much earlier date. We have at present no means of estimating the pace of the march of evolution, and it is not surprising that geologists, impressed with the apparent slowness of present change and the number and variety of the forms which played their part on this earth's stage, have felt disposed to demand almost illimitable time in order to bring the drama to the scene of which we are the spectators. But hints have of late been given that its action may sometimes be quickened, so that the sedimentary rocks, though their rate of deposit involves many uncertainties, may give us a little more guidance.

It has been suggested that for these rocks one foot in a century may not be an unfair estimate for their average accumulation. If that be so, and we take their total thickness since the beginning of the Cambrian Period, when the remains of living creatures are neither very obscure nor extremely rare, to be 183,000 feet (an estimate which I think does not err on the side of parsimony), the total time from the beginning of that (the Cambrian) period would be only 18,300,000 years. At present it is very difficult, for reasons on which we must not dwell, to estimate how much more would be required for the formation of the underlying strata. According to one estimate, this would bring the total thickness up to 266,000 feet, and the time to between 26,000,000 and 27,000,000 years. This, however, must be largely increased by masses of rocks which once were stratified, but have since undergone great mineral changes, and by others the origin of which is more uncertain; still, so far as can be inferred from the evidence tendered by the crust of the earth, a hundred million of years would be ample time, though a fifth of that time would be quite inadequate.

Sir G. H. Darwin estimates that the time which has elapsed since the moon parted from the earth may be about 56,000,000 years, and obviously both the formation of sediments and the existence of life would not be possible till long after this event. Again, Professor Joly has approached the problem from quite another point of view. He assumes that the ocean originally consisted of fresh water; its saltness being due to the dissolved matter which has been carried into it by the water of rivers. From this he concludes that about 90,000,000 years have elapsed since the earth became cool enough to allow water to collect upon it. But for this calculation also he has been obliged to admit some factors which may easily be far from correct, so that his estimate is probably a maximum, and one which may err considerably on the side of excess. But at any rate it shows that geologists cannot complain at being restricted to one hundred million of years for the story of the earth.[1]

Before quitting this subject we shall find it convenient to give a short account of the composition of that part of the earth which can be examined. The original crust must have been formed from materials once molten, and after this had become solid, any changes in it must have been due either to external agents or to the invasion from a lower zone of matter still liquid. The sedimentary rocks have the former origin. The latter, called igneous rocks, from their past history, must be the nearest representatives of the primitive crust, and will therefore be noticed first, though the brief space at our disposal does not allow of any approach to a full description.

These igneous rocks vary much in chemical composition. They consist of silica, sometimes free and crystallised as quartz, but more commonly in combination with one or more of the following: alumina, potash, soda, lime, magnesia, and iron-oxides; the last also being sometimes free. They may be arranged in a

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[1] For a discussion of this and other questions, see W. J Sollas, *The Age of the Earth*, p. 21 (1905).

graduated series, at one end of which are those containing about 75 per cent. of silica, and at the other those with about 40 per cent. In the former case alumina and the alkalies are at least 20 per cent. of the whole; from the latter they are almost absent, magnesia and iron being the dominant constituents. The condition of the material when cooled depends partly upon its composition, partly on the circumstances under which it has become solid. Speaking in very general terms, we may say that a readiness to crystallise is in inverse proportion to a richness in silica; but much also depends upon circumstances, such as the rate of cooling and the pressure under which this occurs. From the same material, as can be demonstrated by experiment, may be formed either the transparent glass of our windows or a white opaque mass of small crystals. Thus it is possible for any rock to be in either a glassy or a crystalline condition; in the latter state, however, the individual crystals may be large enough to be fairly conspicuous to the eye, or their size may gradually diminish till they become indistinguishable, and the whole mass assumes a "stony" aspect like a piece of very compact porcelain or one of the non-transparent glasses. In the latter condition the rock may be either still crystalline, though the individuals are extremely minute and confusedly crowded, or may consist of a vast number of minute crystals crowded together in a residuum of glass. The investigation of these structures was not really possible until rather more than half a century ago, when the microscope was applied by the late Dr. Clifton Sorby to the examination of very thin sections of rocks.

Volcanic eruptions, as will be described in a later chapter, bring to the surfaces samples, sometimes on a large scale, of the molten matter beneath the hardened crust.[1]

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[1] It is of course possible that, as the solid and the liquid state depend upon conditions such as pressure, the amount of water present, and temperature, which may from time to time be varied, the material of the inner part of the crust may pass more than once from the one condition to the other.

These are called lavas, which are sometimes glassy, sometimes in a more or less minutely crystalline condition. Rocks of the same chemical composition, which have cooled at no great distance from the surface —namely, under conditions sometimes very similar to those upon it—will differ little in structure from lavas, though less frequently glassy, but as the depth at which they solidify increases they will become, if other conditions remain the same, more coarsely crystalline.[1]

Petrologists have divided the igneous rocks into a number of species and varieties, but we must be content to mention only two or three of the commoner. A magma with a high percentage of silica and some 20 per cent. of alumina and alkalies, more commonly potash, when coarsely crystalline forms granite.[2] When the rock is very minutely crystalline, presenting a "stony" instead of a speckled aspect, we may call it a felstone; and when it is glassy an obsidian or a pitchstone (the latter having a more resinous appearance). Those lavas, however, which consist of an intimate mixture of minute crystals and glass are generally called trachytes (because they frequently have a rough feeling to the hand).

A magma containing from a little more than 40 to about 50 per cent. of silica, with a low proportion of alkalies, but a fair amount of alumina and a high one of lime, magnesia, and iron, is called a dolerite or a basalt, according to its crystalline condition. And the latter term is popularly applied to all the varieties which are sufficiently compact to look black at a short distance. This material but rarely and locally forms

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[1] Those which we can examine have been subsequently exposed to view by the removal of the overlying rocks.

[2] When soda is the dominant alkali, it bears another name; but as there is no hard and fast division between the two this name may suffice for general purposes. When there is little free quartz and more of the lime magnesia and iron bases, the rocks are named syenite and diorite. Some "practical men" apparently think that almost anything which can be used for paving-stones or road metal can be called granite. That, however, is wholly unjustifiable.

a glass. The older kinds often assume a green colour, and are inclusively called greenstones. The rocks consisting of a still lower percentage of silica with a high one of magnesia and iron-oxides are comparatively rare; seldom, if ever, forming glasses, and, so far as is at present known, they never quite reached the surface. These are called the olivine-rocks or peridotites, and are rather liable to alteration.

The sedimentary rocks must have been derived from the igneous. When the agents of denudation, as will presently be described, act upon such a rock as a granite, the felspar is "rotted" by the removal of its alkalies and other changes, so that it gradually becomes a clay; the quartz, which is a very insoluble mineral, is liberated to form sand, and the other silicates either form some variety of clay or enter into other chemical compounds such as carbonates. Thus the igneous rocks are directly or indirectly the source of the sedimentaries, and the material derived from them is transported by moving water to other places. This process will be described in later chapters; at present it will suffice to say that only those materials which are deposited on the bed of the sea can occupy a large area, and that they will become more finely grained as the distance from the source of supply increases. Thus each sedimentary deposit will be more or less wedge-shaped as the materials change from coarse to fine, so that we may go on from gravel and sand to clay, which ultimately disappears after passing through the state of the very finest mud.

But the deposit of material may still continue, though in quite a different way. In the destruction of rock-masses water carries off in solution some of their constituents, especially silica and lime (the latter as a carbonate), together also with a little sulphur and phosphorus. Living organisms now begin their work, removing from the water all the constituents of which they have need, and making use especially of the first and second to build up the hard frame of their bodies. Silica is removed by the little plants called diatoms, by radiolarians, and by certain sponges—all very low in the scale of animal organisation, but able to construct beautiful though minute "skeletons." The carbonate of lime is built up into another minute group of plants—certain algæ—the tests of foraminifera, generally minute but often wonders of construction, into corals, the shells of molluscs, and other marine and fresh-water organisms. These after death are buried in the sand and mud, thus augmenting its volume, but as the process of life and death is continued in the clear waters, the making of limestone goes on there; since, where the depth is too great for the larger organisms to flourish or even to exist, there is a constant rain of those minuter creatures which have been floating like a cloud in the upper waters of the ocean. Limestones, then, are mainly organic in origin. When formed in the shallower waters they may develop with moderate rapidity, but are likely to be limited in extent, since they require rather exceptional conditions; while in the deep water, since they are formed of very minute organisms, their growth will be very slow. Thus whenever we can follow a deposit far enough from a shore, we may expect to find gravel graduate into sand, and this into clay, which gradually dies out and is replaced by limestone. It is therefore obvious that the deposits, which are strictly contemporaneous records of any one epoch in the earth's history, will differ considerably in their thickness, mineral character, and organic remains. Also, that as the conditions of deposit must change from time to time, the results will show corresponding changes, so that we may find in any one place a variable succession of strata, and may sometimes discover that Nature not seldom destroys what she has constructed, and has torn whole pages out of the life-history of any particular district. In such a case the new deposits will not, as a rule, lie quite evenly on the old; the crust will very probably have been moved, the older strata tilted into a different position, so that the newer sometimes rest upon the truncated ends of the others. Geologists call this uneven fitting an unconformity, and it must always indicate a considerable interval of time. Changes of this kind are accordingly associated with changes in the life-history of the place, so that we must be prepared for palæontological as well as stratigraphical breaks in the succession of strata.

Rocks are grouped together, as the numbers of a periodical are bound into volumes, by making use of convenient changes in their physical and palæontological characters, and we have to do the best we can with a series from which pages and even whole sheets are missing. Thus it follows that a successive grouping of strata adopted for any one district or country may not be strictly accurate for another, or the characters of the several members may be very different. The chalk of England is represented by a fairly strong yellowish limestone in the south-west of France and by a hard sandstone in Saxony; and even where this change has not occurred we cannot prove that the deposits began and ended quite simultaneously in countries some distance apart. Still less can this be done when we are dealing with the larger groups, each of which may be regarded as including several parts or even volumes; and the difficulty of correlation is likely to increase with the distance, because we may expect that in past times the creatures living on the earth would show differences corresponding with the climatal and other conditions much as they now do, though possibly not to quite such a marked extent. It must not therefore be supposed that the geological epochs, periods or eras, have nearly so precise a meaning as they have in human history. As Huxley once pointed out, deposits though homotaxial—that is, occupying the same position in the progressive record of life—may not be contemporaneous in any strict sense of the word; still, as a classification is necessary, we may arrive at one which is sufficiently accurate for practical purposes, though we cannot date the beginning of a geological formation with the same precision as the reign of a king. The divisions in the succession of stratified rocks are drawn at any convenient horizon where there is either an actual gap in the record, or some marked change in the character of the deposit or the fossils suggests that, especially in the latter case, more time has really elapsed than would at first sight be supposed.

The following grouping has been adopted for the strata in our own Islands, and it holds good for the adjacent parts of the Continent, and may be extended, if we allow of a gradually increasing elasticity in the terms, to other parts of the world. Large associated successions of the stratified rocks are called Systems, and the times occupied in their deposit Periods. The Systems are subdivided into Groups and Stages, and their durations are expressed respectively as Epochs and Ages.[1] The fossiliferous systems are associated into three great sets named Series, which are sometimes called Primary, Secondary, and Tertiary, but now perhaps more often Palæozoic, Mesozoic, and Kainozoic—the Ancient-life, the Middle-life, and the New-life eras—to which we must again refer in the chapter dealing with the life-history of the earth. This, then, is a list of the systems in descending order—that is, as they occur in the earth's crust—each above its predecessor in age—together with the general characters of the deposits representing them in the United Kingdom. No sharp line separates the latest from the time when history begins.

	Recent, Prehistoric and Pleistocene	Sands, Gravels and Clays
Kainozoic	Pliocene	Gravels, Sands and soft Limestones
	Miocene	Wanting
	Eocene	Clays, Sands and a little Limestone

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[1] There is unfortunately some diversity in the use of their names, and the proposals of the International Geological Congress in 1881 did not really help to secure uniformity.

Mesozoic	Cretaceous [1]	Soft white Limestone, with sandy and clayey base
	Neocomian	Sands and Clays
	Jurassic	Limestones and Clays
	Triassic	Clays, Sands and Gravels
Palæozoic	Permian [2]	Sandy rocks with some magnesian Limestone
	Carboniferous	Clays, Sandstones and Coals, with Limestones below
	Devonian [3]	Sandstones, Shales and local Limestones
	Silurian [4]	Sandstones, Shales and local Limestones
	Ordovician	Sandstones, Shales (often Slates [5]) ; little Limestone
	Cambrian	Sandstones and Shales, often Slates

Beneath the Cambrian is a considerable thickness of rocks, in which the uppermost differ little from it in mineral character but retain very few, and these commonly obscure, traces of living creatures ; and the lower, though often certainly sedimentary in origin, have undergone so much mineral change that even if living creatures had existed when they were deposited, all traces of them must have been obliterated. These rocks are now commonly called Archæan, and in them we meet with a third great group of rocks, the Metamorphic, or those which have undergone such great changes that it is difficult to determine their original condition. The term should be used only in this sense, for of course hardly any rock is now quite in the same state as when it was deposited. The organic fragments in one of the Jurassic limestones have been cemented

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[1] Some geologists call Cretaceous and Neocomian respectively Upper and Lower Cretaceous.

[2] The Permian and Trias, which in some districts are not easily separated, were formerly grouped together as New Red Sandstone.

[3] As this system is represented over a large area chiefly by Sandstone of a reddish colour, it is often called the Old Red Sandstone.

[4] Some geologists call Silurian and Ordovician respectively Upper and Lower Silurian.

[5] Slates split (from pressure) independently of bedding.

together by the deposit of calcite (crystallised carbonate of lime); even in the apparently unchanged chalk the silica, once disseminated through it in the form of minute organisms, is now aggregated as flints; there is mineral deposit among the grains in a sandstone and slight change among the constituents of an ancient shale. Rocks truly metamorphic often exhibit a parallel arrangement of their component minerals, and are called schists from a tendency to split parallel with this structure. Igneous rocks also may undergo metamorphism, but in consequence of the greater chemical stability of their constituents this is often less conspicuous than among those of sedimentary origin. The agents of change are water, pressure, and heat, of which sometimes the one, sometimes the other, may be predominant. Water produces chemical changes in the mineral constituents of a rock by subtraction, addition, and rearrangements; pressure causes crushing, and thus facilitates in more than one way the attack of water; heat, besides intensifying the effects of the other two, brings about alterations which would be impossible without it. One example only must suffice—the effect of an igneous rock when intrusive in a clay or shale. If the former cools quickly, the latter is simply hardened—nature plays the brickmaker—but with slower cooling, as generally happens when the intruder is a great mass of granite, the mineral character of the other rock may be so completely changed that an aggregate of clayey particles has become a crystalline rock consisting mainly of some kind of mica and quartz. The igneous rocks are also metamorphosed, but as a rule not so conspicuously as the sedimentary; for instance, when water enters into chemical combination with the magnesian silicate in a peridotite, it forms serpentine, well known as an ornamental rock; and when a granite has been exposed to a severe pressure rude cleavage planes are produced, along which mineral changes take place, so that the granite is converted into a gneiss or mica-schist. But some of these two rocks in the Archæan series are probably igneous in origin, and may have acquired the foliated structure at the outset under conditions of cooling very different from the present. If the temperature at the surface were high enough to prevent water from accumulating upon it, the pressure there would be augmented by the weight of the ocean. "In that case the very lava-stream would consolidate under a pressure of about 310 atmospheres, equivalent to about 4000 feet of average rock;"[1] and besides this, the rise of temperature beneath the earth's surface would be much more rapid—for instance, after about one twenty-fifth of the whole time which has elapsed since the first consolidation, the rate would be one degree for every 10 feet of descent. The earlier geologists supposed that sedimentary rocks of a comparatively late geological age might have been converted into crystalline schists and gneisses, but the evidence advanced in favour of this view has always broken down when it has been closely scrutinised, and few would now deny that such crystalline rocks are not only Archæan, but also do not belong to the latest part of that era.

CHAPTER III

THE WORK OF HEAT AND COLD

We may define a rock as an aggregate of mineral particles, generally more or less diverse. In ordinary use the term generally connotes a certain amount of consistency and hardness, but that, strictly speaking, is not the case in geology. In that science, clay or even the sand of a dune are rocks no less than a limestone of the Portland quarries or the granite of Dartmoor. But the materials of which the Earth's crust is formed are, as a rule, fairly hard, so that the geologist often for convenience adopts by implication the ordinary significance, as we shall hereafter do, unless the

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[1] The author, *Foundation Stones of the Earth's Crust*, 1888, p. 13.

contrary is stated. We shall also assume that they are practically free from water.

With these limitations, all rocks expand with a rise and contract with a fall in temperature, and the effects of the strains thus set up are often far more considerable than would be expected by those who live, as we do in Great Britain, in a temperate climate. In regions nearer to the Equator, and especially in lands almost without rain, like the deserts of Africa and Central Asia, where the sky may be clear for weeks or even months together, the difference between the day and the night temperature is often great. For instance, in Western America a difference of 90° F. between the extremes of day and night temperature is not uncommon. At 12° S. latitude in Central Africa, Livingstone noted a maximum of 137° F. and a minimum of 42°, while these on the thirtieth parallel in South Australia are said to be 131° and 24°, which give a range of 107°. Such changes as these, daily repeated, though not always so great, cannot occur without setting up severe strains in the exposed portions of a rock, especially in fragments, where the shape is irregular and little more than one surface is exposed to the sky. Travellers have noted the results of these continued expansions and contractions. Fragments are constantly splitting off from the faces of crags or other exposed masses of rock, and these are again broken up, so that the ground is strewn with sharp-edged angular pieces, which vary in weight from a few ounces to as much as two hundred pounds. Extreme cold would be quite as effective as extreme heat, but the consequences of this cannot be so readily distinguished, because water in freezing expands with great force, and in regions where the rainfall is more normal and the winters are severe, the ice-wedge, as we may call it, becomes a much more effective agent in rupturing rocks than any molecular strains from expansion and contraction in a dry condition. But in dealing with past episodes in the history of the globe we are often unable to prove whether in a particular region the range of the thermometer was great and the rainfall slight, and thus we take it to be probable that important changes of temperature have more commonly produced effects in the past, as they still do in the present, by the intervention of water.

Heat and cold set the air in motion, and are the causes of winds.[1] But winds catch up the lighter materials on the earth's surface and transfer them from place to place. The dust, like "the windy ways of men," is "stirred only to be laid again," but not exactly on the spot which it previously occupied. It is carried through the air, it strikes against obstacles in its course, and sooner or later comes again to rest. Those who live in temperate regions have little notion of the effects, though to some extent indirect, brought about by the winds. Now and then a gale of exceptional strength may devastate our pleasure-grounds and forests; we may see dust careering along our roads or clouds of sand sweeping along a flat shore; we may watch the gradual building up of dunes on our coast or even their slow march inland as they retreat before the invading sea;[2] but these are hardly more than feeble imitations of what can be witnessed in arid regions like the Sahara or the Central Asian deserts. Dust, like a fog, blots out the light of the sun; it fills the air, making respiration difficult; it penetrates almost everywhere; it piles up itself in all sheltered places and against every obstacle. Dunes or sandhills on our own shores are monuments of the transporting power of wind, and their development can often be studied. In the path of drifting sand a tuft of grass may be enough to form a tiny mound; a groyne gathers a bank of sand in its

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[1] For a discussion of this subject, and an account of the air currents, regular or irregular, on the globe, we must refer the reader to any treatise on meteorology.

[2] The tower of the ruined church of Eccles, near Happisburgh in Norfolk, projected from the dunes in 1839 on the landward side of their crest; in 1862 it rose from the bottom of their seaward slope (Lyell, *Principles of Geology*, 11th edition, i. pp. 518, 519). In April 1892 it cleared the dunes by nearly three yards; during a storm, Jan. 23, 1895, it was overthrown by the waves (E. Hill, *Geological Magazine*, 1895, p. 229).

lee, and some accidental check may be the beginning of a dune. Even one of these is seldom long at rest. When the wind is high it drives the sand up the slope on which it impinges, carries the grains over the crest, and lets them come to rest on the other side. Thus a dune is commonly crescent-shaped; its sides, which are the lower, advancing more rapidly than the central part, so that wave follows wave on the surface of the desert as they do on the sea, except that their forward movement is extremely slow.

But the wind-driven dust and sand takes some share in sculpturing the face of the earth. In the National Museum at Washington, according to Sir A. Geikie,[1] is a sheet of plate-glass, once a window in the lighthouse at Cape Cod, which was so worn by the impact of sand grains driven against it by a gale of not more than forty-eight hours' duration as to be no longer transparent. Drifting sand, as I once observed at Barmouth, had in the course of a few years distinctly smoothed the masonry of a stone wall, and on the Fifeshire coast had actually polished the surface of a projecting hummock of basalt. Its effects are greater in a region like Egypt. The limestone rocks are furrowed and hollowed out by the desert sand. The face of the Sphinx is comparatively smooth on one side, on the other it is deeply grooved; for the stratified mass, from which it was hewn many centuries ago, is unequal in its power of resistance, and in the latter case exposed to the prevalent winds. The abrasive power of wind-driven dust and sand is amply illustrated in the Egyptian and other deserts. Its effects, perhaps, may occasionally have been a little over-estimated, but it is undoubtedly an agent of some importance in producing changes more or less superficial, developing structures latent in rocks or corroding them into strange forms. If a bed here and there be harder than the rest, it may ultimately stand out from the face of a cliff in a sharply defined ridge or, if little more than a lenticle, may bring about the formation of a pinnacle capped by a protective

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[1] *Text-Book of Geology*, p. 436 (1903).

turban. Drifting sand also sometimes wears away the surfaces of rounded pebbles which are most exposed to its action, and gives them a definitely angular form. If the pebble was originally egg-shaped, and the winds are very persistent in direction, its cross-section may become a triangle, so that these smoothed and wind-worn stones are inclusively called *dreikanter*, though the number of their faces may exceed three. Another effect is produced, but it is on a much smaller scale and on the sand grains themselves. Quartz, of which they often mainly consist, is a very hard mineral, and its surface, when it is first removed from such a rock as granite (commonly its original home), is slightly irregular. When such grains are transported by water, as we shall presently describe, they are very slowly rounded, because the fluid acts like a lubricant in preventing friction, but when they are driven along by the wind they are constantly impinging one on the other and on any projecting rock-surface till they become models in miniature of a pebble on a beach. Thus a geologist, when he finds a sandstone in which many of the grains are well rounded, has little doubt that, even if it is not directly of desert origin, these in some past period of their history have been driven about by the wind. Such grains may be recognised in some of the oldest stratified rocks,[1] showing that even in those remote ages the winds swept over barren sands as they continue to do at the present time.

In some regions the advancing dunes or the accumulating dust completely buries fields and forests and even, as Sven Hedin and Stein have recently described, the works and homes of man. Many geologists believe that the peculiar sandy earth, which in some of the more central parts of Europe lies like a cloak over the rougher features of the country, often to a height of some 1200 feet above the sea-level, and is called *loess* by Continental geologists, is really a wind-borne dust, like that of Turkestan and some districts in Northern

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[1] *Quart. Jour. Geol. Soc.*, xlvii. (1891), p. 90; Brit. Assoc. Rep., 1886, p. 612.

China; where, as Richthofen informs us, it sometimes exceeds 1500 feet in thickness, and has been carved into deep valleys and precipitous ravines with cliffs 500 feet in height, in which dwellings have been excavated by the inhabitants of the region.

CHAPTER IV

THE WORK OF RAIN AND RUNNING WATER

RUNNING water is the most important of Nature's graving tools. It destroys, transports, and deposits; its action in each of these processes being partly chemical, partly mechanical. The three come in the order enumerated, but their operation is sometimes all but simultaneous. Rain, when it falls from the sky, is almost pure water, for in its descent it can absorb only a small quantity of air with a little carbonic and other acids, with some sodium chloride—especially near sea-coasts. It also brings down floating dust, whether inorganic or organic, the former especially in the neighbourhood of large towns where the air is polluted by the smoke of countless chimneys. But however pure rain water may be when it descends upon the earth, it will be found before long to have taken up mineral substances varying with the nature of the ground over which it has passed, and to be sweeping onwards mud, sand, or gravel, according to the velocity of the stream.

We are prevented by the limitations of our space from describing in detail the distribution and amount of rainfall and the laws by which these are governed. It must suffice to say that they depend upon the currents of the atmosphere, the shape of the land surface, and the relative position of the seas. Thus, in England, winds from western to southern quarters often bring rain because they have taken up moisture in passing over the Atlantic, while winds from the east are commonly dry because they have made a long journey overland, where their expenditure has much exceeded their receipts. Thus the annual rainfall in Norfolk and Cambridgeshire is about 23 inches, while on the lower ground in Southern Lancashire it is at least 10 inches more. The rainfall is increased by hills rising in the path of moist air-currents; for instance, its annual average is nearly 38 inches at Manchester, and over 51 inches about the Woodhead reservoirs (800 feet above sea-level) on the western side of the Pennine range. Some regions of the earth, such as the Sahara and similar deserts, are almost rainless, while in others the fall is much greater than in any part of the British Isles; though in some of the mountainous districts it may vary from 60 to 80 inches, and at Seathwaite in Borrowdale (the wettest place in Britain) is slightly more than 129 inches. But the wettest place in the world, so far as our information goes, is Cherrapunji in the Khasia Hills, where the annual rainfall amounts to at least 472 inches—or nearly 40 feet—the larger part of which descends during the monsoon—that is, in about four months of the year. Here as much as 40·8 inches has been measured in a single day.

When a building is fresh from the mason's hands the surfaces of its stones, where so desired by the architect, are smooth, but in old buildings these have become rough to the touch. On a limestone such as one from Portland, Bath, or Ketton, tiny fragments of shells and little rounded grains, from which the rock gets the name of oolite, become conspicuous to sight and touch; projecting grains of quartz make a sandstone like a rasp; the polish disappears from marbles, porphyries, and granites, and the last of these after many centuries may even begin to crumble. The falling rain smites the surface with its hammers, tiny but persistent, and as the old proverb says, "constant dropping wears away stones"; it sinks into the rock wherever that is permeable, and sets up chemical changes which destroy its coherence. The rain no sooner collects into streamlets than its action though now localised is intensified. In some of the streets of Cambridge a runlet of water flows along the gutter. In fine weather this is clear, and before sanitation was regarded people might be seen filling their kettles in front of their own doorsteps. But after a heavy shower the water is muddy, for the rain has carried with it the dust from the street. Thus every brook and every river runs more swiftly after wet weather, and the volume of the water increases more rapidly when the fall of rain has been heavy. Rivers, ordinarily sluggish, quicken their pace and become turbid with mud; the swifter sweep along sand and gravel coarser than that usually moved; and in mountain regions we may stand by the swollen torrents and listen to the "grumbling" of boulders as they are hurried onwards. During this process fragments broken from neighbouring crags gradually lose edges and angles by friction and mutual impact; for the making of mud, sand, and pebbles is mainly a result of mechanical forces, though, as we shall see, chemical action plays some, though a variable, part in the work, and these forces are at work, not only on the surface but also underground.

At this place it will be convenient to mention two cases, in one of which the action of water, speaking in general terms, is wholly mechanical, in the other wholly chemical. Earth-pillars are the best examples of the former. These are pinnacles of a stiff, stony clay, capped by a cushion-like boulder. Occasionally they are isolated; more often they form linear groups. Two very noted examples occur in upland valleys a few miles from Botzen in the Italian Tyrol. A little examination shows that they have been carved out of a much larger mass of clay by runlets of rain as they hurried down either side of the valley towards the central stream. In fine weather the path of these is dry and the clay is hard; after heavy rain it is softened and a little stream runs down every furrow. The bigger boulders act like an umbrella and protect the clay beneath from being washed away, but when one falls off the unprotected pinnacle is gradually destroyed. In the Alps these earth-pillars often vary from about

4 to 8 yards in height, but in some places, as in the Sierra Nevada, they are much more lofty. But they may also be, and are so frequently, on quite a small scale. Such miniature pillars, often only one or two inches high, may sometimes be found in our own Islands; in fact they may be looked for whenever a rather stiff clay contains fairly flat bits of stone.

Sand-pipes, as they are called, are the best instances of the direct chemical action of water. These occur most frequently in chalk, but are occasionally found in other limestones, where they also have been covered with a sandy gravel. Into the latter rain water has sunk, has made its way down to the chalk, and has begun to dissolve this, at some "vulnerable" point, forming a cup-like hollow. As this is gradually deepened it is kept filled by sand or gravel slipping from above, and may thus be prolonged downwards to a depth of several feet, while it is enlarged sideways, though much more slowly.

The corrosive action of rain and of the atmosphere generally is conspicuous in limestone districts such as the hill regions of the Mendips, Derbyshire, or Western Yorkshire, where the bare rock is pitted, furrowed, and sometimes traversed by channels (a feature especially noteworthy in the Eastern Alps) which sooner or later, like the gutters along house roofs, end in a pipe plunging downward into the rocks. The surface of the limestone is bare; the furrows afford shelter to ferns and other Alpine plants. Sometimes, however, where these are shallow and the rock contains but little insoluble material, hardly a tuft of grass or any herbage mitigates the austerity of the landscape. But where the structure of the rock permits the rain to remain on the surface long enough to be gathered into rills, these may form brooks, which however are at last swallowed up. Here a "pot" or natural shaft is formed, down which the water plunges, thus adding a mechanical to its chemical action. These shafts are common in districts where the limestone is pure, compact, and thick, and nowhere more so than in the district around Ingleborough;[1] Gaping Gill, one of the most noted, engulfing a stream perhaps half a dozen yards wide and usually a few inches deep. The shaft here is rather more than 300 feet deep, and expands at the bottom into a bulbous shape.

The water swallowed up in these natural shafts continues its underground course, carving out a channel for itself, so that many districts have a subterranean as well as a subaerial drainage system, streams combining down below just as they do upon the surface, and it may often be that the former system is on the larger scale. Here also the work is obviously to some extent mechanical, but that it is mainly chemical is proved by the fact that caves are either unimportant or altogether wanting in any but limestone regions. Sometimes a river which has cut its way down to a bed of rock more than usually permeable disappears from sight, leaving a channel which is only used in times of flood, and perhaps afterwards it emerges to resume a subaerial path. That happens to the Manifold, near Ilam in Derbyshire; and in any part of our Islands, where that thick mass of pure grey limestone which belongs to the lower part of the Carboniferous system comes to the surface, swallow-holes, caves, and subterranean streams are likely to be found. This is also true of any similar kind of rock in other parts of the globe. The fine caves of Le Han in the Belgian Ardennes, and the more gigantic Mammoth Cave of Kentucky, are striking instances of those occurring in the Carboniferous Limestone; while in the Jura and in most of the valleys in the Limestone Alps the traveller sees streams leaping out from the face of a cliff or emerging full-born on the bed of a glen. The water swallowed up on the higher ground has made its way by subterranean channels, which are no doubt often enlarged into caves—those at Adelsberg in Carinthia are on an exceptionally grand scale—until at last its course is intercepted by a valley and it again returns to the light of day. Instances are common enough in

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[1] See Boyd Dawkins, *Cave Hunting*, 1874, chap. ii.

our own Islands. In the ponds among the gardens near Wells Cathedral copious springs spout up, which are fed by the rain that has been swallowed up on the Mendip Hills; the Axe, when it emerges from the cave by the hyæna-den at Wookey Hole, has been supplied, at any rate in part, by water swallowed up on the hills in the neighbourhood of Priddy; and the stream which plunges down Gaping Gill returns to the light of day on the bed of a valley near the village of Clapham, not many yards away from a line of caves which it must once have excavated. As a rule, the subterranean channel cannot be followed for the whole distance from intake to outlet; it may be too narrow or low, or blocked by fallen rocks; but, notwithstanding this, the connection between the two ends can in many cases be placed beyond reasonable doubt, if not actually demonstrated.

The fact that various mineral substances are present in a greater or less amount in the water of springs and rivers is another proof of its action on the rocks over or through which it passes. As already said, when rain reaches the earth away from the polluting atmosphere of towns, it is practically pure water, but that of streams, lakes, and springs contains in solution an appreciable quantity of mineral salts, which prove by their amounts and differences that they have been derived from the rocks over and through which the water has been running. For instance, the Scotch Dee, above Aberdeen, contains 312 parts of mineral matter in 10,000,000 of water; the Rhine, near Bâle, 1712 parts; and the Thames, at Ditton, 2720 parts in the same amount. Of the solid matter in the first river, 205 parts are salts of lime or magnesia, 122 of them being carbonate of lime. Of that in the second, those salts form 1607 parts, 1279 being carbonate of lime; and in the third river the proportions are 2302 and 1684. It is easy to account for these differences. The Dee flows over crystalline rocks, the constituents of which contain but little lime (for though marble is among them, its amount is relatively small), and are but slightly soluble in ordinary water. The Rhine is fed by streams from the

Alps, where limestones are abundant as well as crystalline rocks, and the river system is on a much grander scale than any in Britain. Thus, not only is the proportion of dissolved mineral salts much higher than in the Dee, but also that of the carbonate of lime fully ten times as great, while the rise in the corresponding percentage of the Thames water, though it is a shorter river, is mainly due to its having traversed sedimentary rocks, the constituents in which are rather more readily attacked by reason of their fine state of division and the loose texture of the limestones, especially the chalk. An idea of the quantity of material thus removed from the basin of the Thames may be obtained from the fact that on an average its waters carry in solution 1000 tons of chalk daily under Kingston Bridge. As the volume of a ton of chalk is about 15 cubic feet, this would be enough in the course of a year to form a solid mass 365 feet long, 150 feet broad, and 100 feet high.

Springs afford confirmatory evidence. Everyone knows that the water is "hard" in limestone districts, that is, contains much dissolved carbonate of lime. This is often deposited as "tufa" when a spring comes to the surface and the soluble bicarbonate is converted by evaporation into the insoluble carbonate. That is the origin of the "petrifying" springs so common in Derbyshire and other limestone districts. In this way, as may be seen for instance near Matlock, masses of tufa are formed large enough to be quarried. This is done on a still greater scale by some of the rivers issuing from the western slopes of the Apennines (mainly limestone). The chief buildings of Imperial Rome were constructed of travertine, which has been deposited around and below Tivoli by the Anio and other streams; and the grand ruins of the three Greek temples at Pæstum consist of a coarse tufa formed by water from the neighbouring uplands. Other, and less common, kinds of mineral springs admit of a similar explanation. The brine wells of Cheshire, Staffordshire, and Worcestershire, are supplied from the rock-salt dissolved by their waters in percolating through the Red Marls, where it was in all probability deposited from an inland sea. By processes of this nature a vast quantity of soluble material must be conveyed from the body of the earth to its surface, over which it is transported to such seas and to oceans. The mineral constituents in these must have been derived, with slight exceptions, from the solid matter in the earth. They may alter their relations, may enter into new combinations, but they cannot be spontaneously generated in the water.

Vast quantities also of material, as already implied, are transported by the mechanical action of water, and are swept along as mud, sand, or gravel; the amount depending partly on the strength of the stream, partly on the nature of the rock over which it flows. Tables often quoted show that a current, going at the rate of 15 feet a minute, can move soft clay; fine sand will be carried along by double that velocity, and stones as large as big peas by the treble of it. Currents flowing from 135 feet to 200 feet a second can transport pebbles from 1 inch to 1½ inches in diameter. We must not forget that the moving force of running water varies as the sixth power of its velocity, so that if the latter be doubled the former becomes 64 times as great. If it can roll along a stone in the one case an inch in diameter, this will be 4 inches in the other. Thus the material moved at flood times is much coarser than that ordinarily transported, so that gravelly seams in a mass of sand may be regarded as the records of exceptionally heavy rains in the remote past. The amount of material thus transferred also depends on the nature of the rocks over which a river passes. One flowing over clays, shales, and soft slates is generally more or less muddy, but where the rock is hard, like some sandstones or limestones and most crystalline rocks, the water is clear except after heavy storms. The limpidity of the streams is one of the most attractive features in the valleys of the Italian Alps, near Monte Viso, where glaciers have given place to permanent snow-beds.

Thus torrents, as we can see in many Alpine valleys, sweep along boulders and coarse gravel, as well as the sand and mud with which their waters are turbid, dropping the heavier material whenever the current slackens, but transporting the lighter till that also becomes burdensome. Experiments have been made to determine the amount of material which is actually travelling down the channel of a river, and a study of the flat beds of valleys and of the deltas formed in lakes and seas leads to a general estimate. But the quantity, it must be remembered, in any river varies at different seasons. The Rhone, for instance, is believed to transport when low one part (by weight) in 7000; when at its mean height, one in 2000; and when in flood, the same in 230 parts. The Ganges, before joining the Brahmapootra, is said to be transporting annually enough sediment to cover 172 square miles with a layer one foot deep. But the Mississippi brings down to the sea enough to cover to the same depth 268 square miles, and the Hoango could do this with no less than 730 square miles; the material in all cases being partly in suspension, partly pushed along the bottom by the moving water. The flat valley-beds on the course of many rivers are formed by material which they have dropped on their journey, and it is still augmented when they overflow their banks. The cultivated land of Egypt, as Herodotus observed between twenty-three and twenty-four centuries ago, is "the gift of the Nile"; the level plain separating the Lakes of Brienz and Thun has been built up from a depth of fully 700 feet, with debris brought by the Lütschine from the Oberland, and to a less extent by the Lombach torrent from the valley of Habkern. The delta of the Rhone is gradually trespassing on the upper end of the Lake of Geneva, and its margin is now half a league in advance of its position in Roman times. The Adige and the Po have been extending Italian territory at the expense of the Adriatic, and the delta of the latter in one place has done this so rapidly that Adria, which was a seaport nineteen centuries ago, is now 14 miles inland.

Thus rivers demolish, transport, and build, but their effects on the whole are more destructive than constructive, because they remove so much material which they do not obviously restore. If time enough were given, rain and rivers would ultimately plane off all inequalities from the land—would bring it down to a dead-level, and spread it out over the floor of the sea. The ocean, in fact, is the grave of the land. Some of the transported material is dropped on the way, but this halt after all is only temporary—gravitation, aided by water, will again be at work upon it. Some will be added to the land as an irregular fringe, and still more will be carried many miles away from this and spread over the floor of the sea, gradually diminishing its depth; but most if not all the matter dissolved in the river water is carried away into the ocean, where it maintains, or rather increases, the saltness of the sea, and supplies to living organisms the minerals which their solid parts require, such as silica for the diatoms, the radiolarians, and many sponges, and carbonate of lime for most foraminifera and mollusca. Some idea of the quantity of the latter mineral thus invisibly transferred may be obtained from an estimate made many years ago by Bischof, that the Rhone annually discharges into the sea enough carbonate of lime to make more than 332,500 million full-grown oyster-shells. Thus the chalk which the Thames and the Colne have secretly "conveyed" from the hills of Eastern England is once more restored to a solid form in the oyster-beds of Whitstable and Colchester.

From what has already been said, it follows that rivers make the valleys rather than, as many formerly supposed, the valleys make the rivers. Movements in the earth's crust are of course necessary to set the water to work, and to counteract its levelling tendency. Folds, and even certain kinds of fissures, in the rocks may be helpful in determining its course, but this is regulated by gravitation rather than by gaping cracks. The process of erosion and its changes can usually be most readily understood by following the course of a valley from its beginning in a mountain region to its emergence on the lowlands. For instance, in many parts of the Alps the upper pastures are smooth slopes of turf. On these the herbage has a protective effect —enough to prevent the rain from washing away the soil or gathering into rills. Sooner or later, however, the latter is accomplished, and the continuity of the slope is quickly interrupted by a little furrow. As the area drained is enlarged and these rills are combined, the furrow is deepened and widened, so as to become a more conspicuous feature on the mountain side, Presently the stream in cutting downwards may encounter some harder stratum, which causes it to set up a plunging movement. That, where circumstances are favourable, may initiate a waterfall, but it will in any case modify the shape of the glen. This, when the rock is rather friable, has a V-like section, for as the bed is deepened the sides slip down, but where the rock is strong this action almost ceases, cliffs replace the slopes, and the valley becomes a gorge. As the angle of descent diminishes, and the brook, augmented by tributary streamlets, grows into a river, the valley is widened, for the stream begins to oscillate and to press more on the sides than on the bottom of its bed. Under these circumstances a section of the valley (apart from any change of form due to deposit on its bed) is gradually altered from a V to a kneading-trough. The slope of the sides is generally different, because the velocity of the water is not identical in all parts of a river channel; it is greater at the surface than at the bottom, and, if the stream be straight, greater in the middle than at the sides. Hence with a curving channel the line of quickest motion transgresses toward the concave bank, on which the water presses rather more strongly than on the convex one. Thus the slopes of a valley are generally steeper on the concave side than on the convex. But in studying these features we must bear in mind that the volume and the velocity of the river have not always been constant, and thus be prepared for what may at first sight, be regarded as anomalies. The valleys, for instance, in our English lowlands must have been excavated, and their dominant contours have been impressed upon them by much larger rivers than those at present flowing along their beds.

In several such valleys, especially in South-Eastern England, beds of coarse gravel, often of considerable thickness, may be found to at least 100 feet above the present level of the water. These were evidently deposited by the river when it was flowing at a corresponding height above its modern channel, along which also it can only transport alluvial mud, except possibly during a very high flood. Besides this, the true floor of the valley sometimes lies many feet below that now visible; so much so that it may even be below the present sea-level. Thus the river in its days of youthful vigour must have carved out a channel for itself, which afterwards in an enfeebled phase it could no longer keep clear and is now filling up. A channel choked with drift is hidden beneath the present bed of the Thames at London, of the Humber at Hull, of the Mersey at Liverpool, and sometimes away from any course visible on the surface.[1] The alluvial flats on either side, as these rivers approach their estuaries, are significant of a loss of power and a consequent dropping of their burdens. One cause of this has obviously been a lowering of the land, which has diminished the velocity of the current, but another has been a change in the volume of the stream. When these coarse gravels were deposited, both the snowfall in winter and the total annual precipitation were greater than they now are. All through the spring, and in some regions well into the summer, the rivers were kept flowing strong and full; here wearing down their beds, there overflowing

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[1] Hidden valleys, filled with drift to depths from 60 to over 100 feet below ordnance datum, have been occasionally found. The most remarkable case was at Glemsford in the valley of the Stour, above Sudbury, where 477 feet of drift was pierced before reaching the chalk. See F. W. Harmer, *Quart. Jour. Geol. Soc.*, lxiii. (1907), p. 494.

their banks to drop sand and gravel on either side, so that such an one as the Thames must have swept along for some months in every year, with a strength which it now manifests only for a day or two, perhaps half a dozen times in a century.

Changes such as we have mentioned, in the level of the land, in rainfall, and in climate generally, make the story of the sculpture of a country complicated and sometimes difficult to interpret. It is like a palimpsest, on which the process of erasing and rewriting has been more than once repeated, so that the earlier records can hardly be deciphered. In illustration of this we may mention a district the features of which long perplexed geologists. This is the Weald of Kent and Sussex. From the South Foreland to Beachy Head a line of chalk downs sweeps round through Hampshire; their inner slopes descending steeply to a fairly wide valley which separates them from a more sandy and generally lower range, and their outer shelving down more gently in the direction of their planes of bedding shown by the included layers of flints. This valley is excavated in the Gault, a soft dark clay, and its inner boundary is formed by a range of brownish sands and sandstones with a little clay—the deposit often called Lower Greensand. This second range encloses another and much wider valley, something like the imprint of a horse-shoe, which is carved out of the Weald Clay, and within it, to represent the "frog," rises a group of hills chiefly sandstone. Each of these ranges occasionally overtops the 800-foot contour line, while the floors of the enclosed valleys usually lie between those of 150 and 250 feet. This district, since the rocks are older towards the middle part, must have formed part of an elliptical dome which once extended across the Channel into France, but has now been severed and to no small extent effaced by the sea. This was formerly supposed not only to have isolated the smaller French from the larger English portion, but also to have in some way or other scooped out the valleys, so that the steep inward-facing chalk cliffs were regarded as memorials of an ancient coast-line. This explanation more than half a century ago was shown to be untenable by C. Le Neve Foster and W. Topley.[1] On the northern side of the area (for this will suffice to illustrate their method of reasoning) the drainage from its interior zones is carried to the Thames by the Wey, the Mole, the Darent, and the Medway, all of which cut completely through the North Downs. In the valley of the last-named river old gravels, evidently once deposited by it, may be traced to a height of sometimes 300 feet above its present level. These gravels indicate that, speaking in general terms, the bed of the Medway, together with its tributaries, must once have been higher than it now is by about that amount, and the same is true of the other river systems. There is ample evidence to show that all this work must have been done while the land was above sea-level, so that rain and running water must have deepened the Wealden area by some 300 feet. But the physical features of the upper part are similar to those of this lower one, so that we are justified in inferring that even if the top of the dome was planed off by the waves when first it rose from the sea, the existing system of hills and valleys must be attributed to subaerial agencies.

In a region undergoing denudation of this kind streams struggle one against the other. The more active of two flowing in opposite directions cuts back more quickly into the intervening watershed, thus tending to lower its crest, to push back the dividing line into its neighbour's territory, and ultimately capture some of its tributaries. The Alps afford many notable instances of this kind of trespass, but it also occurs, though less obviously, in Britain. Another form of trespass is exhibited when one of the branches of a river system cuts back into the ridge separating it from the main channel of another one, "taps" the latter, and by diverting the whole of its water leaves the part below dry till streamlets from either flank combine to supply another but feebler occupant.

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[1] *Quart. Jour. Geol. Soc.*, vol. xxi. (1865), p. 443.

When a dome-like area of stratified rock is being gradually upheaved, the water which runs off it naturally follows the line of quickest descent, thus taking a radial or "transverse" course. But when this intersects beds alternating in hardness, as in the region of the Weald, the rain which falls on the exposed surfaces of the softer outcrops gradually lowers these, as it more slowly makes its way—for it will find one somehow—to one of these transverse furrows, and thus excavates another set of valleys more vague and irregular in outline, gradually removing these softer materials, and leaving the harder rising on either hand as lines of hills. As this second set of valleys follows the general direction (or strike) of the strata, they are called longitudinal valleys. In the Wealden district they follow the outcrops of the Gault and of the Weald Clay, and in some parts of the Alps a geological map shows that a river makes more than one change from a transverse to a longitudinal course.

CHAPTER V

THE WORK OF SNOW AND ICE

Ice no less than running water is an agent of denudation, transport, and deposition. When the air temperature falls below the freezing-point, rain is replaced by snow, which lies upon the ground till warmer weather causes it to melt. When the mean annual temperature of a district is below 32° F., the snow will not all be liquefied, and there will be more or less accumulation. In equatorial regions, where the temperature at the sea-coast never descends to the freezing-point, snow and ice are unknown, but in high latitudes running water is a rarity, often only to be found in summer. But snow may be seen, even in the Tropics, because the air becomes gradually cooler in ascending from the sea-level. The rate at which the mercury of the thermometer drops is not quite uniform, but about 3° F. for each 1000 feet of ascent is a rough approximation.[1] The elevation at which the snow, instead of being completely melted away, just manages to linger through the summer, is called the snow-line, and it more nearly corresponds with a mean annual temperature of 30° F. than of 32° F., because the frozen material loses slightly by evaporation even during the coldest weather. If then the mountains in a tropical region rise high enough, their upper parts will be snow clad. Suppose, for instance, the mean annual temperature at the seacoast to be 75°, the snow-line would be at or slightly under 15,000 feet, and all mountains that exceeded this elevation—like, for instance, the principal summits on the Ecuadorian Andes, which vary from about 15,500 feet to 20,500 feet—would be snow clad to much the same extent as peaks in the Alps which range from 8500 feet to 13,500 feet, for in the latter chain the snow-line ranges, according to latitude, from slightly below 8000 feet to nearly 9000 feet. So that in the Oberland there will be permanent snow on any summit which overtops the former limit, and on the higher peaks rain rarely or never falls. But on these the snow does not accumulate indefinitely. When the slopes are steep the loose new-fallen material slips away from the frozen surface of the older, which has anchored itself to the irregularities of the underlying rock, and slides down to the upland glens beneath. Such a discharge is called a dust-avalanche, and these are common after a spell of bad weather in summer or at the beginning of winter; but when the approach of the former enables the mountains to throw off the burden of snow which has been laid upon them by the latter, this slips away in huge more or less hard-frozen slab-like masses which plough their downward way through forests, obstruct roads, and bury villages, so as to be much the more destructive to property and life. These are called from their

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[1] As a rule the fall is slightly more rapid, and sometimes 1° for 300 feet would be rather more exact. At Ben Nevis it is 1° for 277 feet.

closer texture "ground-avalanches." Both, however, sweep along with them fragments of rock, earth, and other material, thus transporting and depositing as well as destroying.

But there are many parts of a mountain where avalanches would not be very effective in relieving the accumulation of snow. They could carry it from the crags to the upper parts of valleys, but the beds of these would not slope rapidly enough to rid themselves of the burden by a second set of avalanches. When snow falls on a fairly level surface, like a flat-topped mountain or the head of an upland glen, it accumulates layer upon layer. The surface during fine weather melts a little, the water trickles down into the underlying mass, and is there again frozen. The pressure also of the upper layers upon the lower causes these to consolidate, and thus the texture of the snow-bed is by slow degrees changed into fairly solid ice. This is the beginning of a glacier. The head of an elevated mountain valley forms a reservoir occupied by snow which is in process of conversion into ice, and which is prevented from indefinite accumulation by a slow downward movement of the frozen material, which may be said to creep along the bed of the valley by the action of gravitation. On the history of that change, the physical cause of the motion, and the precise nature of glacier ice, we have not space to dwell; it must suffice to say that the movements of this ice resemble those of a plastic solid (for instance, some kinds of wax or even clay), which is rather easily ruptured by strain, but is readily re-cemented when fragments are pressed together. Thus any inequality of movement (and this is more rapid in the central part of the ice-stream than at the sides) or irregularity in the slope of the valley—anything which sets up a distinct strain—causes fissures, or crevasses, as they are called, to open. If, for instance, there is a sudden descent—a rocky step—in its bed, the glacier may be almost broken up into a wilderness of white crags, parted by blue chasms—affording often scenes of weird beauty. Such a part is called an ice-fall.

So long as the glacier is above the snow-line its volume is more or less augmented, but below this limit it dwindles as it descends into the warmer air, until at last it is altogether melted away.[1] The great Aletsch glacier is much the longest in the Alps, for it is rather more than 16 miles; others, like the Unteraar, the Gorner, and the Mer de Glace vary from 8 to 10 miles, but the majority are considerably shorter. In fact every stage may be found, from a glacier which is little more than a *névé*-basin, and that a small one, to the long ice-stream supplied by great reservoirs of snow like one of those just enumerated. These grander flows of ice descend between pine-woods and grassy alps to about 4000 feet (and formerly some 600 feet lower) above sea-level, but the smaller often do not extend for more than about a thousand feet below the snow-line, and as a rule a glacier does not begin to form till about the same amount above this limit. Its place of birth and of death are, of course, at a less distance from the sea-level as either pole is approached. In Scotland the snow-line would be at about 5000 feet, so there are neither glaciers nor, strictly speaking, any permanent snow.[2] But in the north of Norway mountains lower than Ben Nevis are draped with snow and give birth to glaciers, which descend almost, and in one case quite, down to sea-level. In this district the mean temperature is about 36° F., so the snow-line must be near 2000 feet, and the glaciers take their origin about 1000 feet higher—that is to say, the conditions here are similar to those in an Alpine district where the higher peaks rise rather above 12,000 feet. In Greenland, where the mean annual temperature is only just above 32° F. in the extreme south, the glaciers increase rapidly in volume, and descend in latitude 64° 50′ from

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[1] The rate of motion is dependent on more than one condition. In the Alps it averages about a foot a day, but the corresponding advance of great Greenland glaciers is 20 feet or even more.

[2] Ben Nevis, the highest mountain, is 4406 feet. The mean annual temperature is barely 31° F., and though a little snow may remain near its summit, it is only in places sheltered from the sun.

a divide of unbroken snow between eight and nine thousand feet above sea-level down into the fjords, where they terminate in great cliffs of ice, and huge blocks are detached which sail away to increase the dangers of an Atlantic voyage. When valley glaciers expand and become confluent at the foot of a mountain range, as on the Alaskan coast at the foot of Mount St. Elias (18,092 feet), they receive the name of Piedmont (or Mountain-foot) glaciers; when they largely, if not wholly, cover even the inequalities of the uplands, they are called Ice-sheets. Such may be seen in Arctic and Antarctic regions.

Rock debris detached from peaks and precipices falls upon the surface of a glacier and is carried along by it. Most of that from the crags on either side comes to rest on or near the edge, and thus forms a kind of stony selvedge. This is called a lateral moraine. Where the ice-streams from two valleys are united to form a single glacier, the moraine on the left bank of one joins that on the right bank of the other, thus producing a single moraine which, as it is now more or less in the middle of the ice-stream, is called a medial moraine. Small fragments of rock, by absorbing heat from the sun, tend to sink into the ice, but large accumulations, like those in a moraine, have a protective effect, so that the ice underneath becomes higher than that exposed on either side. Thus a medial moraine takes the form of a mound, the lower parts being ice and the upper a mass of broken rock and grit, which at a distance presents a rude resemblance to a railway embankment. But when the glacier is badly broken this regluarity of form soon disappears, much of the debris being engulfed in the crevasses and the rest scattered over the surface. Large isolated boulders, by acting as parasols, protect the ice immediately beneath them, and thus, in course of time, become supported by pedestals of it a yard or so high. These are called glacier tables. The blocks and the grit, which continue to travel on the surface, are ultimately dropped at the end of the glacier, where they also form a stony mound, which is called a terminal moraine; and if the ice has anywhere made a long halt this mound may reach a great size.[1] In the same way a lateral moraine may be stranded by the retreating ice, and may also form a mound on the slope, if that be not too steep, which runs parallel with the bed of the valley. If, however, a glacier advance after a halt, it will push part of the moraine before it and "override" the rest, but to this phase in its history we will return.

Large boulders which have become isolated from a moraine are sometimes dropped by the retreating ice on the sides or bed of a valley. These "erratics" are often common, and when poised in rather unstable positions are called "perched blocks." They are scattered over the parts of England which, as said above, have been in some way exposed to the action of ice,[2] and are frequent in the Alps, whence they may be traced over the adjacent lowlands. They show how much more extensive were the glaciers of this chain during the Ice-Age, for boulders from the northern slopes of the Pennines and the southern of the Oberland may be traced down the course of the Rhone to within a few miles of Lyons. Some of these are very large, such as the Pierre-à-bot, near Neuchâtel; the Pierre des Marmites, above Monthey; and the Blauenstein, near the Mattmark See (Saas-thal); the least of which must exceed 40,000 cubic feet.

The debris swallowed up by the shallower crevasses may be disgorged after a time upon the surface of the glacier, but a considerable quantity is engulfed by the deeper, carried down to the bottom, and then pushed along by the moving ice. Thus the latter, which of itself could only act as a burnisher, is converted into a file, wearing away the rocky floor, smoothing off

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[1] Those deposited by the ancient glacier from the Dora Baltea valley (Piedmont) are like lines of hills, some of them rising at least 1000 feet above the lowland.

[2] In England instances occur of enormous blocks of chalk and other rock which have been in some way or other transported by the action of ice (the author, *Presidential Address to the British Association*, 1910, p. 19).

projections, and replacing an angular by a rounded surface, which sometimes may even be polished, but is often also scratched and scored by the stony teeth.

Thus the rounded surfaces, called from their peculiar outlines *roches moutonnées*, more poetically compared by Ruskin to the backs of plunging dolphins, and the "handwriting on the wall," exposed by the retreating ice are unmistakable, and may be traced in many mountain regions, like the Alps, Scandinavia, and parts of our own country, far below the level of existing glaciers, or even in districts from which they have completely disappeared. The debris overridden by advancing ice may not only be pushed along beneath it, but also entangled in its lower part, and this happens to a greater extent in polar regions, where the ice-streams, in consequence of the oblique incidence of the sun's rays in summer, terminate in cliffs rather than in slopes. Besides this, the ice-file, as already stated, wears away a certain amount of debris, which also is transported, and if not swept away by subglacial streams is ultimately left, together with the other material. This, which as a whole contains a larger amount of "rock-flour" and finer debris than the ordinary terminal moraine, has been called "ground moraine." Its total amount and its ratio to that carried on the surface depends on local circumstances, and is no doubt larger in the case of ice-sheets than of ordinary valley glaciers,[1] and the proportion will increase with the area covered by ice, because the fewer and smaller the projecting crags, the less will be the quantity of ordinary subaerial moraine. At one time geologists were apt to exaggerate the amount of ground moraine, but it is sometimes a factor which must not be altogether neglected.

We must now glance at the material called boulder

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[1] The manner in which the debris becomes entangled in such a country as Spitzbergen is well described by E. J. Garwood and J. W. Gregory (*Quart. Jour. Geol. Soc.*, vol. liv. (1898), p. 197). See also T. C. Chamberlin, *Glacial Studies in Greenland*, Parts i.–x.; *Jour. Geol.*, 1894–7.

clay. This, so far as it can be precisely defined, consists of a clay, sometimes more or less sandy, in which larger fragments of rock are embedded. For instance, these, in the boulder clay of the eastern counties of England, consist of chalk, generally in well-worn pebbles, with pieces, often more angular, of other limestones, flints, sandstones, and crystalline rock, in a matrix which has obviously been largely derived from the Oxford or the Kimeridge Clay. Many of the fragments must have come from rocks which outcrop in the northern counties or in Scotland, but some must have travelled from Norway. The origin of these boulder clays, whether they have been mainly formed by great ice-sheets creeping over hill and dale, or by ice floating in the sea, as will presently be described, has been for many years a subject of controversy, on which we have not space to enter, and must content ourselves with saying that it is not yet so completely settled as some partisans of the former appear to believe.

In polar regions the sea rapidly freezes over at the coming of winter to a depth of from two to three yards. When a cake of ice forms against the shore (an "ice-foot"), its base encloses beach shingle, which as the frozen mass moves up and down with the tide is ground against that frozen to the land. Where the latter ends in cliffs, large masses of rock are detached from these by sudden frosts, which fall or slide down upon the ice, and this, which at a greater distance from land is called floe-ice, breaks up at the coming of spring into huge cakes, which float away with their cargoes of debris towards lower latitudes. These ice-floes and the bergs from glaciers are often of great size, especially in the southern hemisphere, and must distribute their burdens as they gradually melt away over large areas of the sea-bed, to within 35° to 40° of the equator, coming nearer to it in this than in the northern quarter.

A few words must be said before quitting this subject about the melting away of glaciers. As one of them descends below the snow-line its surface is melted by the sun, especially in summer. The water thus formed quickly gathers into streams which carve for themselves channels in the ice as they would do in ordinary rock, but with this difference, that any one of them is engulfed when a crevasse opens across its path. It plunges down to the bottom of the glacier, wearing for itself a sort of shaft, called a moulin, and as stones are often carried down by the falling water and "churned" about by it, the rock beneath is presently excavated and "potholes" are formed. Some very fine examples of these "giants' kettles" (*Riesen-töpfe* or *Marmites de Géants*) as they are called, measuring sometimes half a dozen yards in depth and width, may be seen in the sandstone over which ice once passed, at a place called the Glacier Garden, near the Lion Monument at Lucerne. In some of them the large rounded boulders which have aided in the work of excavation are still lying.

It is therefore obvious that ice, where it is formed, is an important agent in modifying the surface of the globe. Indirectly glaciers do much by feeding large rivers and preventing them from drying up during the heat of summer, by supplying their waters with abundant sand and mud for transport to distant regions, and with gravel, often extremely coarse, which is deposited nearer to the mountains. It is obvious, from what has been already said, that glaciers must lower their beds, but to what extent they have done it has been, during the last half century, a much-disputed question. Sir Andrew Ramsay in 1862 claimed that the larger Alpine lakes (and *à fortiori* those of smaller size in that and similar mountain regions) had been excavated by ice. This hypothesis commended itself to not a few geologists, but it has been criticised by many observers, not less well acquainted than its distinguished author with glaciated regions. These, while admitting that under certain circumstances mountain tarns and some small lakes may have been thus eroded, maintained the difficulties against claiming such an origin for the larger Alpine lakes to be very serious. The hypothesis has of late years been carried to an extreme, against which

Ramsay himself would probably have protested, and the glaciers of the Alps have been credited with having deepened their valleys during the ice-age, sometimes by at least a thousand feet. It is needless to say that this hypothesis is yet more vigorously repudiated by the opponents of lake-excavation, who deny that any proof can be produced of ice, though an agent of some importance in abrasion, being able to do much in erosion.[1] Time will show which of the two schools has most accurately interpreted this chapter in the more recent history of the earth, and whether the work of snow and ice is nearly so important in sculpturing and transporting as that of rain and rivers.

CHAPTER VI

THE WORK OF THE SEA

The sea, like the rain and the rivers, is an agent of denudation, transport, and deposition, and they are in reality dependent on it. From the sea they come, drawn up into the atmosphere by the sun, and to it they return. Its waters cover rather more than seven-tenths of the surface of the globe,[2] and if this were perfectly smooth they would form an outer shell a little less than two miles in thickness, or, if separated, a ball nearly 850 miles in diameter. The winds raise waves on the surface of the sea which, though powerless in its greater depths, wear away, as will be described, the margin of the land. Differences in the amount of

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[1] Ramsay's paper on the origin of lakes appeared in *Quart. Jour. Geol. Soc.*, xviii. (1862), p. 185. It was criticised by the present writer in vol. xxvii. 312; xxix. 382; and xxx. 479. The valley-deepening hypothesis is advocated by Penck and Brückner, *Die Alpen in Eiszeitalter* (1909); and criticised by the author, *ut supra*, vol. lviii. 690, and *Presidential Address to the British Association*, 1910. The literature connected with the subject is voluminous.

[2] The proportion usually given is 0·71.

heat received from the sun set up currents; the action of those, however, must be more or less superficial. Those in shallower waters produce denudation like rivers; but in the great depths of the ocean, though here also movements initiated by differences of temperature must continue, these in all probability are so feeble that a very slow accumulation is the only change.

The action of the sun and moon, as described in books on astronomy, causes tides[1] or periodic fluctuations in the ocean level. Since the difference between high and low water increases as the water becomes shallower, the ebb and flow may considerably augment the denuding and transporting power of the water. The currents also of the larger rivers can still be detected at considerable distances—that of the Amazon perhaps so much as 300 miles from land—so that they must thus carry to long distances some of the finer mud.

The ocean bed is irregular in form, but for a description of this we must refer to books on physical geography, and be content to say that sometimes it descends very gradually, as it does in the neighbourhood of the British Islands, where no part of the North Sea, except a submerged channel off the Norway coast, exceeds 100 fathoms in depth, and that contour line runs about 35 miles west of Valentia and more than 200 miles in the same direction from the Land's End. The edge of this submarine plateau is within a shorter distance of the Biscayan and Iberian coasts, but after passing it the descent generally becomes steeper, though, as we have said, if the Atlantic were dried up it would be possible to drive from the Land's End to Newfoundland, and that is true of other oceans. Much of that ocean exceeds 2000 fathoms, and some parts even 3000 fathoms; but it only once (to the north of the West Indies) attains 4660 fathoms in depth. In the

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[1] In the open ocean the rise and fall of the tide is not more than 3 or 4 feet, but the difference increases as the water shallows, and it may amount in certain gulfs or estuaries to from 10 to over 20 yards. In such cases the movement up and down, twice in the day, of a large body of water must produce important effects.

Pacific, however, there are hollows still more profound, soundings between 4000 and 5000 fathoms being comparatively numerous, and the greatest known depth (to the east of the Kermadec Islands) 5155 fathoms. This distinctly exceeds the greatest height of the land, Mount Everest (slightly over 29,000 feet); and there is also this difference, that, if a cast of the earth were made, the mountains would be represented by furrows, but the ocean depths by plateaux.

The waves act upon the land like great water-hammers or battering-rams. Their power on exposed coasts is always great, and becomes tremendous during storms. At Skerryvore lighthouse, some 10 miles away from Tiree, the average pressure of the waves in the summer months is estimated at 611 lbs. on the square foot, and during the winter at 2086 lbs., while on one occasion (March 25, 1845) this rose to 6083 lbs., or 2 tons 14 cwt. on the same area. It is not then surprising to read that at Whalsay, in the Shetland Islands, blocks weighing from 6 to 13 tons have been detached during storms from their places on cliffs fully 70 feet above the sea, and others nearly 300 cubic feet in volume have been torn from a rocky shore and thrust up its acclivity for a distance of 40 or 50 yards. Thus the waves carve a rocky coast into crags and skerries, as we can see in many parts of our coasts, not only in the softer rocks like the chalk of Kent and Yorkshire, but also at the Lizard, the Land's End, and "Tintagel Castle by the Cornish sea." The Stag's Leap at Freshwater Gate, Old Harry north of Swanage, the Parson and Clark at Dawlish, St. Michael's Mount, and other insulated masses farther west, are all remnants of land which has been eaten up by the sea. Where the rocks are still less capable of resistance, its inroads, even in comparatively sheltered regions like the North Sea, are often formidable. It is rapidly encroaching on the Yorkshire coast in the neighbourhood of the Humber, and on those of Norfolk, Suffolk, and Kent, notwithstanding the efforts made in many places to check its ravages. The site of Roman Cromer is said to lie some two miles out at sea; Dunwich which was an important place in the reign of Edward I, has been reduced to a village sheltering itself in a valley running into the land. Some distance up this one small church is still in safety; of the eleven others, the ruins of the last, the eastern end of which twenty years ago was more than five yards from the edge of the cliff, have now lost two or three bays. Great inroads have been made at Southwold and Pakefield; in fact it is estimated that the annual loss in some places on the Norfolk and Suffolk coasts averages two feet.[1]

Not only do the waves break off fragments from the rocks, but they also undermine the cliffs, causing further falls. The harder materials are banged and ground one against another by the waves, and thus converted into pebbles, which they sweep along the shore, here piling them up as shingle banks, when they may have a protective influence, there carrying them into deeper water. But these heavier materials rarely travel far. At the depth of a few fathoms the waves almost always, and the currents generally, are incapable of moving more than sand and still lighter materials. So much depends on local circumstances, such as the nature of the sea-bed and of the coast, that it is impossible to be precise in any brief statement, but we may say that the deposits, as we recede from the land, should be, and generally are, in the following succession: first shingle, next gravel, then sand, and lastly mud, beyond which comes a broad area in which terrestrial debris, as we have already implied, plays but a small part. Here the remains of organisms, generally minute, accumulate in the deep and undisturbed bed of the sea. These are mostly calcareous, small algæ and foraminifera, with occasional contributions from corals and molluscs, but are also siliceous, such as diatoms, radiolarians, and spicules of sponges. This globigerina ooze, as it is called from a foraminifer usually abundant in it, were it upraised, would much resemble the chalk of our

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[1] See, for instances, W. H. Wheeler, *The Sea Coast* (1902), chapter vii.

English hills. It extends to a depth sometimes as much as 2900 fathoms; more often, however, when well beyond 2000 fathoms it passes into an amorphous reddish clay, the only organisms in which are some annelids and radiolarians. Here and there before reaching this last area oozes are found consisting of diatoms or pteropods, or containing a mineral called glauconite (a hydrous silicate of alumina, iron, and potash), which is precipitated, as on the Agulhas Bank, within the foraminifers, thus forming a rock which would resemble the Upper Green Sand of South-east England. The origin of the Red Clay, in which concretions of manganese oxide are formed, has been disputed. Some have regarded it as consisting of the finest variety of mud, drifted from the land, which, however, is improbable; others as a chemical precipitate in the foraminiferal tests, which have been afterwards dissolved by the sea water; while others consider it to be the detritus of pumice, which, after floating on the ocean surface, has become waterlogged and sunk to the bottom, where it has been joined by meteoric dust. Be this as it may, the depths are being filled up, but as a rule very slowly; and though here and there fairly marked inequalities may be noted in the ocean's bed, resembling submerged cliffs or river channels, these are generally not far from the land.

The ocean level has obviously altered much since the geological record began. One cause of this may be a sinking of the land, another a rise of the sea. These, it may be remarked, are not always convertible terms, though both are due to a change in the form of the earth, for a part of the land may have its distance from the centre diminished or increased, and the sea may do the same in consequence of an alteration in the shape of its bed, besides being affected by one or two other, though minor, causes. Obviously, then, the zone of marine denudation advances or recedes, and that of deposition, whether mechanical, chemical, or organic, must be correspondingly affected.

As regards the former, the main difference between the sea and a river as a denuding agent is that the one planes and the other furrows. Stages in the latter are sometimes marked by steps, or terraces, more or less distinct, on the sides of a valley; in the former by the same along the side of the land. As this is rising from the sea, the waves at each pause forthwith proceed to cut a groove or cliff or slope, depending on the coherency of the materials. These, together with the beaches at their foot, may sometimes be found some distance, perhaps a few hundred feet, above the sea-level. On the coast of Chili they are said to occur in places as high as nearly 1300 feet, and changes of this kind must have happened in comparatively recent times along a large part of the western coast of South America. On the same side of Scotland a terrace-like raised beach is conspicuous, in many places 25 feet above the sea, and signs of others may be detected at a higher level. The former also may be traced rather nearer to the sea along several parts of the British coast.

From what has been said, it follows that the tendency of the sea, whether in denuding or depositing, is to produce level surfaces on a large scale. In the former case it may meet with masses of rock harder or more capable of resisting attack than their neighbours, so that they may be left as islands, from which the sea may have to retreat before it can reduce them to the general level. This, for instance, would be the condition of the Channel Islands, if the sea-bed were elevated by much less than a hundred fathoms; but all the new land surface around them would form, as a whole, a gently shelving plain, in which the rivers flowing over the present land surface would proceed to carve channels. Again, if a corresponding portion of the sea-bed within the zone of deposition were upraised, it would present a similar or even more uniform contour. The plains of Holland, though here it is rather the sea which has been excluded than the land which has been upraised, may serve to illustrate the effects of submarine deposition.

CHAPTER VII

VOLCANOES AND THEIR LESSONS

A VOLCANO is formed by the discharge, more or less explosively, of material, most of which is or has been in a molten condition, from an opening in the ground. Around this that material is piled up to form a hill, sometimes comparatively low, called a cone, at the top of which is a bowl-like hollow—the crater. The cone is often wholly built up of slaggy or rough fragments—named volcanic ash, or scoria, or *lapilli,* or pumice if very cellular, siliceous, and light in colour—though occasionally it consists only of overflowed molten material called lava, but very commonly (especially in the case of large volcanoes) of a mixture of the two, lava either flowing in streams from the crater, or more frequently breaking out from some fissure in the side or at the base of the cone. Thus volcanoes afford several varieties of form and structure, as will presently be indicated, and may illustrate every phase, to use a metaphor, from the activity of life to the rigidity of death, in which case the corpse may exhibit all stages of dissection.

In the British Islands no example of an active volcano can be found, for, though during past geological ages eruptions were far from rare in one part or another, they have so long ceased that some of their most obvious features have been destroyed. Cones and craters are better preserved in the Eifel district of Germany and in that of Auvergne in Central France, but no volcano, still active, can be found nearer than Southern Italy or the neighbouring islands. We may find it convenient to select, as the first example, a volcano which is comparatively small, has well-defined boundaries, and generally shows some signs of activity. The conditions are fulfilled by Stromboli, one of the Lipari Islands, about thirty-eight miles from the Calabrian coast, which is often called "the weather-glass of the Mediterranean." The highest point in its rim is 3090 feet above the sea, and, so far as can be ascertained, it is wholly built up of scoria and lava. In one respect, however, the volcano is not quite normal, for it discharges at present not from the centre of its original crater ring, but from three or four small orifices, very near to each other, on its north-western side, where the original rock-wall has been shattered by later explosions. From these marginal craters a cloud of steam, blackened with volcanic dust and scoria, is ejected to heights sometimes as much as 400 feet, and the debris comes raining down over an area surrounding the centre of discharge. This habit of frequent but comparatively innocuous explosion is called a Strombolian phase of volcanic activity. But even here, now and again, it is interrupted by one of greater violence, when large quantities of dust, scoria, and even blocks up to a yard or more in diameter are discharged, together with splashes of liquid lava which solidify in falling—the so-called volcanic bombs. These have formed a black slope —the Sciarra—leading from the mouth of the craters to the sea, down which they may sometimes be seen rolling like red-hot cannon-balls. On ascending the mountain or examining from a boat the low crags at its margin, we find no rocks other than volcanic; and as the island slopes down for nearly 600 fathoms to the general level of the sea-floor, it has probably been built up from that depth in a cone well over 5000 feet high. The other islands of the Lipari group have a similar origin, but only one of them, by name Vulcano, is occasionally active.

Vesuvius, generally an attraction, but sometimes a terror, to Naples, is much better known than Stromboli to the world at large, but its boundaries are less definite, for on the more western side it is closely connected with a great group of minor cones—the Phlegræan Fields—and on the east and south-east merges with a mountainous region, composed of sedimentary rocks—part of the Apennines. Vesuvius, like Stromboli, retains a large fragment of an ancient crater—Monte Somma—the highest point of which is 3640 feet above sea-level, but here the vent still active is more nearly central in position, and is rather higher than the other.[1]

Vesuvius has a very interesting history, because, in the year 79 of our era, it suddenly awoke one August day after a slumber so prolonged that not even tradition had preserved the memory of an eruption, and it celebrated its renewal of work by a destructive orgie, of which the younger Pliny has given such a graphic account. In less than a day the volcano had blown away about half the crater ring of Somma, had buried part of Stabiæ and the whole of Pompeii beneath volcanic ash, had overwhelmed Herculaneum beneath a stream of mud, which afterwards set like a cement, had destroyed an immense amount of property and many hundreds—the exact number is not recorded—of lives. Since that date eruptions, sometimes hardly less severe, have occurred at uncertain and occasionally rather long intervals, during which perhaps nothing more than a little steam escaped from the crater. That of December 1631 was noteworthy for the emission of a large quantity of lava, which broke out at nearly 3000 feet above the Mediterranean, and flowed down the slopes in no less than seven streams, one of them taking its course to the sea through Torre del Greco, about two-thirds of which it destroyed, together with some 18,000 lives, there or elsewhere. Since that time there have been several severe eruptions, the record of the later part of the eighteenth century being particularly bad. Such eruptions, more or less violent after rather long intervals of repose, are called the Vesuvian type.

Of this a remarkable variety has recently attracted special attention. The islands of St. Vincent and Martinique in the West Indies are both formed of

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[1] Exceptionally violent eruptions have more than once reduced the height of the cone by more than 400 feet, after which quieter discharges have again built it up to at least this distance above Somma.

volcanic materials, and each is crowned by a fairly large crater; that in the former island being named the Soufrière, and that in the latter one Mont Pelée. Both had been at rest for not much less than a century, and lakes had formed in each—no uncommon thing in ancient craters. On May 7, 1902, the Soufrière, after some warnings, broke out into violent eruption, and on the next day Mont Pelée followed its example. In both islands large areas were buried beneath scoria, dust, and mud (no lava was emitted, so far as is known), but the most terrible feature was the sudden discharge of an enormous quantity of extremely hot dust, which was more fatal than any plague of Egypt to herb and tree, to beast and man. The loss of human life in St. Vincent is estimated at nearly 1600, but in Martinique the glowing avalanche swept down upon St. Pierre, when the people were thronging to church on Ascension Day morning, and in a few minutes a flourishing city was a heap of ruins, and some 28,000 of its inhabitants had perished. Only a small part lay outside that path of destruction, within which hardly any living person escaped, the only one unhurt being a prisoner, who was so closely immured that the burning dust failed to make its way into his cell. A similar explosion, though on a rather smaller scale, was witnessed, on the evening of July 9th, by Dr. Tempest Anderson and Dr. J. S. Flett from the deck of a vessel moored off St. Pierre, and they only just managed to escape its path. It started from a gap in the lip of the crater, rushed like a glowing avalanche down the upper slopes of the mountain, and then drifted above them as a dark cloud, showering down dust and scoria, still hot. Such is now called a Peléan type of eruption.

Mont Pelée, however, not content with its discharge of incandescent dust, afterwards exhibited a phenomenon which, so far as known, is without a parallel. In July 1902 a mass of solid lava began to be protruded slowly from the crater, like a cork about to be discharged from a bottle of soda-water. This, however, did not happen, for though " the spine " continued to rise till it had reached a height of nearly 2000 feet, it rapidly scaled away, until in the spring of 1907 it had become little more than a heap of ruins at the top of a dome of broken rock.

The fine dust from these volcanoes has often travelled for long distances. That from the Soufrière on May 7th fell thickly at Barbadoes, 120 miles away, and it repeated the effort in October 1902 and March 1903, as it had already done in May 1812. Cotopaxi, on July 3, 1880, when the late E. Whymper was making his second ascent of Chimborazo, suddenly ejected a black cloud of dust to a height of about four miles, which was carried by the winds across the sixty miles' interval between the summits, and began to settle down upon the latter a short time after he had arrived upon it. The dust of Vesuvius has fallen in Montenegro, at Tripoli, and even at Constantinople.[1] Krakatoa, in the Strait of Sunda, which in 1883 broke a long silence, not only covered the adjacent sea with pumice, and sent quantities of dust to Batavia, ninety-four miles away, and six miles farther to Buitenzorg, but also is supposed to have shot the finest material to a height exceeding twenty-five miles, from which it so slowly settled down as to make the circuit of the globe at least once, and to produce the wonderful sunset glows which attracted so much attention in the late autumn of that year.

The lava solidifying in the throat of a volcano is a common feature in its closing days. It may be said to die from an obstruction of the gullet. The elements then begin their destructive work: they tear down the crater, and sweep away the materials of the cone, till at last the plug forms the highest part of the mountain. That is the case with Aconcagua, the culminating summit in the whole chain of the Andes, and with more than one lofty volcanic peak in its immediate neighbourhood or in the Ecuador group. In Auvergne, though cones and well-preserved craters are common,

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[1] The dates and authorities are mentioned in the *Encyclopædia Britannica*, art. *Volcano* (11th edition).

the Pic de Sancy (the highest summit in the district, for it is more than 6000 feet above sea-level) has lost all trace of a crater, and in the more southern part of Scotland volcanic necks, as they are called, the more or less dilapidated ruins of cones, generally small, are very far from rare. North Berwick Law is one of these, Arthur's Seat is another, though its precise history is a mater of controversy, and many can be seen in all stages of dissection, either in the crags or on the beach of Fifeshire.

As was said above, lava, in struggling to reach the surface of the earth, makes its way along fissures, often nearly vertical, in which ultimately it becomes solid. Sometimes, when these are numerous and the neighbourhood suitable, it wells forth from them in great sheets many hundred square miles in extent. That has happened in Idaho and adjoining districts in the United States, where an area, said to be hardly less extensive than France and Great Britain together, has been buried under vast sheets of basalt, sometimes to a depth of over two thousand feet. During a distinctly more remote geological period similar discharges, though on a rather less gigantic scale, occurred in Antrim, the Inner Hebrides, and part of the adjacent mainland, and these outbreaks affected, though sometimes only locally, a district estimated at about 40,000 square miles. To this date belongs a group of important dykes[1] in the North of England, one of which, the Cleveland dyke, runs for some ninety miles across country[2] from Armathwaite almost to the sea near Maybecks in Yorkshire. Sometimes also the molten material thrusts itself horizontally between the beds of stratified rock, and after it has become solid, may be compared to a paper-knife pushed between the pages of a book. Such intrusions are called sills, and

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[1] Wall-like masses of igneous rocks, which do not always reach the surface, are called dykes when the fissure runs evenly and is nearly vertical, and veins when it branches.

[2] This assumes three dykes which are not continuous to be, as is highly probable, really identical.

often are not at first sight easily distinguished from sheets of lava which formerly have flowed upon the surface and subsequently been covered by sedimentary deposits. In another mode of intrusion, generally more limited in extent, the molten material lifts the overlying strata in the form of a low-crowned arch, thus taking a shape something like that of a mushroom. Intrusive masses of this kind, called laccolites, were first noticed in the Henry Mountains of the United States, and they have been detected since then in other countries, including Great Britain. It is possible, indeed, that some of the larger masses of granite, like those of Dartmoor, may really be laccolites on a large scale instead of being boss-like in shape, enlarging rather than contracting in extent in a downward direction. The earth's crust, in fact, sometimes is not only partly built up of horizontal masses of once molten rock, but also is traversed, pierced, studded, and strengthened by others, which vary, as has been described, in texture and chemical composition.

CHAPTER VIII

MOVEMENTS OF LAND AND THEIR RESULTS

Processes of denudation, whether by streams or by the sea, tend, as we have shown, to lower the level of the land, so that, if time enough were given, all its irregularities would be worn away. But this does not altogether happen; there are stratified rocks in many regions on the earth's surface which are proved by their fossil contents to have been laid down below, perhaps very far below, the surface of the sea, but which are now high above it. The shells of marine molluscs now extinct have been dug out of the so-called London Clay on the slopes of Hampstead and Highgate. The chalk of the North and the South Downs consists of organisms which lived in the sea, and was probably formed at a greater depth from the surface than it is now above it. Fossil shells are found high up on mountain ranges, as on the top of the Diablerets (10,650 feet) in the Western Alps, and over 16,000 feet in the Himalayas. Hence one of two things must have happened : either the surface of the sea must have sunk, or that of the land must have risen. Possibly both may have occurred, but to what extent the change may be attributed to the one cause or the other can be more easily determined after a brief review of the facts.

Evidence of upheaval must be more common than that of depression. We can trace a bed by its fossils from the present sea-level to a height of many hundred feet above it, but we can only ascertain what lies below that level by boring or by mining. Coal, for instance, is formed of plants which, as a rule, must have lived in fresh-water marshes, and thus must have grown a little, though it may not have been much, above sea-level. Now coal seams are sometimes worked at least 3000 feet below it. Not seldom marine and fresh-water deposits are found to alternate. For instance, in the South-east of England the so-called oolites—marine in origin—pass up through estuarine deposits (which themselves indicate an oscillation between sea and land) into a great succession of fresh-water beds, which sometimes exceed 2000 feet in thickness, the well-known Hastings Sands and Weald Clays. These are followed by a group of marine sands and clays, which in England are called the Lower Greensand, and to this succeeds the blue clays of the Gault and the Upper Greensand (also marine), which are followed by the soft white limestone of the Chalk. This succession proves that an area, once occupied by the sea, must have been for a long time sufficiently raised above it to become the delta of a great river, and have afterwards been again submerged to an even greater depth than before. These facts may suffice, but the story might be continued to prove the occurrence of similar changes during still later chapters of the earth's history, and it is repeated in almost every part of the earth and through all the ages of geology, so that the words of Tennyson[1] are no poet's dream but an expression of a scientific fact:

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

These changes in the relative level of the earth and sea have not only occurred in the past but also are probably still in progress. Now and again, after an earthquake, the land is found to have been lifted up or dropped by a few inches or feet, and sometimes variably on either side of a fissure, as, for instance, in Japan or New Zealand. There is a well-known case, often quoted, near Pozzuoli in the Bay of Naples. A short distance from the sea are the ruins of a building, generally called the Temple of Serapis, of which three columns, made from a Greek marble called cipollino, are still standing. Their bases are now very slightly below sea-level; their shafts, for the next 12 feet, are yet smooth, but for the next 9 feet are pierced with boring molluscs. It is known that the building was intact during the third century of our era, for it received new decorations from the Emperor Alexander Severus, that it probably fell into ruins during or soon after the fifth century, and that, prior to 1530, the sea washed the base of the cliff which rises some little distance inland, though it had then begun to retreat. Since that time there has been a much greater upward movement, and now one in the opposite direction has apparently begun. Here, however, the area affected may not be large, and be connected with the neighbouring volcanoes, but it seems to have been now established that there is a slow but unequal rise of the land in Southern Sweden and a similar subsidence on the coasts of Newfoundland and Labrador.[2] In tropical seas not a few islands show that coral-reefs have been raised, often from 20 to 80 feet,

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[1] "In Memoriam," cxxiii.

[2] The evidence is quoted in Sir A. Geikie's *Text-Book of Geology* (1903), p. 380.

above the water, and sometimes, as in Cuba, for quite 1000 feet. Yet at Funafuti, one of the Ellice Islands, a boring was put down for rather more than 1100 feet, which indicated a depression about equal in amount to the upheaval in Cuba.[1] Again, rocks bored by lithodomous molluscs, incrusted by barnacles, serpulæ, and corallines, or worn and grooved by the action of the waves, may be found at considerable heights above sea-level, and raised-beaches—beds of pebbles and sand, containing occasionally marine organisms, and identical with those which can be found where the waves are still breaking—are common on many of our coasts, from Cornwall to the North of Scotland, at various heights up to at least 25 feet above sea-level. In the latter country similar raised beaches may be seen at about twice and four times this height. Platforms and caves, worn by the waves at the foot of cliffs, can often be noticed on the western coast and islands of Scotland. At several places on the estuary of the St. Lawrence sea-shells, differing little from those still living nearer to its mouth, occur at various elevations up to quite 500 feet, and the bones of whales, with other marine creatures, have been found in the neighbourhood of Smith Sound at heights up to rather more than 1000 feet above the sea.

By examining the relations of the stratified rocks over larger areas we are able to infer the nature of the movements to which they have been subjected. In the south-eastern part of England, to which reference has already been made, we find, in travelling from London to Brighton, the chalk of the North Downs dipping northwards.[2] So do the underlying strata—the Upper Greensand, the Gault, the Lower Greensand, and the Weald Clay, till we come to the Hastings Sands. In the last the beds for a time follow the same rule, then they bend over in a kind of arch and are inclined toward

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[1] Reef-building corals, as a rule, do not flourish at a depth exceeding 150 feet.

[2] The dip of an inclined stratum is measured by the angle which it makes with the plane of the horizon. Its line of intersection with that plane is called the strike, and the one with the surface of the ground, the outcrop.

the south, after which we find the same strata, but in reversed order, dipping in that direction. Hence as these strata must have been deposited one above the other, almost, if not quite horizontally, they must have been subsequently bent into a low-crowned arch, during or after which process—probably to some extent in both—they have been subjected to great denudation, which has removed huge masses of rock, so that the widely separated chalk hills of the North and South Downs remain like the abutments of a broken arch. But this is not all. The chalk of the North Downs, after disappearing beneath the sands and clays of later date, which underlie London, rises again in the Essex and Hertfordshire hills, and is usually struck, if a boring be put down, at the depth of less than 150 feet beneath the metropolis. Thus the anticline of the Weald, which can be traced for some distance on the eastern side of the Strait of Dover, is succeeded by the syncline of the London basin.[1]

The Pennine range, which extends into Derbyshire from the northernmost part of England, proves the occurrence of movements on a yet larger scale and with rather more complication. In the hill district of that county a mass of grey limestone forms a kind of saddle, dipping to the east on one side of the crest, to the west on the other. On each of these it is succeeded by a thick series of shales and sandstones, which is followed by another one containing important deposits of coal. The original continuity and horizontality of these beds becomes plain on examination, so that here also the crust of the earth has been bent. Similar movements, accompanied sometimes with important fractures and displacements, called faults, can be shown to occur in many places.

But the movements of the earth's crust, especially in mountain chains, are sometimes more complicated than those which we have been describing. Places may be found where a portion of it, in outline a broad

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[1] Beds which dip in opposite directions from a central axis are called anticlinal, and if towards it, synclinal.

strip, sometimes more than a hundred miles in length, has evidently undergone great compression, which must be the result of lateral thrusts, though the exact cause of these cannot always be readily ascertained. The effect may be illustrated by supposing a number of rather stiff rugs to be laid one above another on the ground between two boards, one of which is steadily impelled towards the other. These rugs will pucker up in folds, which will become sharper as the process is continued, and in some cases one fold might become doubled back upon the other. If the material of these layers were less flexible than carpet, they might at last be unable to bear the strain, and a rupture might occur near the crest of a fold, after which one part might be pushed forward over the other. In many mountain ranges cases of overfolding and thrust-faulting, as these are called, are far from rare, and they have sometimes produced an apparent sequence in the strata which is quite illusory. Examples of these may be found in many parts of the Alps and, nearer home, in the Highlands of North-west Scotland. In the latter it was for a long time supposed that a group of comparatively unaltered strata, some of which contained fossils, were overlain by another which had undergone very important mineral changes. Had that been true, the beds which lay at the top must have been affected by subterranean heat and other agents, producing alteration much more than in those beneath them ; while the real fact was that a group of more crystalline rocks had been thrust over another much later in date, and the perplexities had been increased by certain modifications during the process.

These corrugations, fractures, and slidings of wedges in the earth's crust, one above the other, are far commoner in mountain regions than was formerly supposed, and the failure to recognise them often led to very erroneous ideas as to the thickness of deposits and the possibilities of metamorphism. For instance, it was supposed that the stratified rocks in the southern uplands of Scotland occurred in an orderly upward succession, and attained a thickness of fully 14,000 feet. But Professor Lapworth demonstrated, nearly forty years ago, and his work has since been confirmed by the more detailed investigations of the Geological Survey, that the same beds are repeated several times in closely compressed folds, thus reducing the total thickness to a few hundred feet.[1] Again, in that mighty wall of rock which forms the northern face of the Bernese Oberland, gneiss apparently alternates with limestones or shales of Secondary age, but in reality great wedge-like masses of the older rock have been forced through the broken folds of the newer. Even apart from these complications a little study of the Alpine rock-masses proves them often to exhibit folding on a gigantic scale. In the district just mentioned the grand precipices of the Wetterhorn, together with its northern peak, consist of limestones, but the middle and southern peaks are formed of the ancient crystalline rock; and this is also the case with their neighbours, slightly farther south, the Schreckhorn and the Finster Aarhorn, in which that rock, though formerly buried beneath the above-named sediments, now overtops them in the latter peak by a thousand feet. The range of Mont Blanc affords a yet more conspicuous instance of folding. Its upper part is formed of ancient crystalline rock, while the valleys of Chamonix and Courmayeur are excavated in slaty beds of Secondary age. The one rock rises some 15,700 feet above sea-level, the other barely attains 7000 feet. A little study shows that in the Mont Blanc Aiguilles and the ranges of the Brévent and the Mont Chétif, to the north and south respectively, we can recognise the shattered cusps of three enormous folds, while the slaty beds above-mentioned are the remnants of their troughs.

Besides the conspicuous displacements, indicated by great and often repeated flexures of the earth's crust, large blocks of it are often either raised up or dropped

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[1] Folds which follow on such close succession that their cusps point in the same direction and their sides are nearly parallel are technically called isoclinal.

down, without any crumpling. Such displacements may be produced by an arching of the crust between two positions rather far apart, the result being the formation of one or more set of fractures, and a settling down of the broken masses either into the underlying void or on to more "pasty" material below, till they again arrive at positions of equilibrium. When the plane of fracture is either vertical or slopes down beneath the dropped portion, the fault is called a normal one; but if the slope is in the contrary direction, it is said to be reversed. The former obviously is more likely to be the result of a strain and the latter of a thrust. When the strips of crust formed by a number of parallel normal faults are let down continuously more and more in either direction, this is called step-faulting; and a modification of it, the dropping of a long strip of the crust between two parallel faults or groups of faults, is named a trough-fault. As faulting obviously brings into juxtaposition two very different kinds of rock, it has a great effect on scenery, and trough-faulting on a large scale may give rise to valleys.

For instance, the Valley of the Jordan takes its origin from two nearly parallel faults or groups of faults which run southward from Lake Huleh (the ancient Merom) to the Gulf of Akabah, whence they may be traced southward towards the lake region of Central Africa. In most parts of the area thus affected careful study is needed to detect the displacements; but in others, according to Professor J. W. Gregory,[1] these are so recent that the fault-face is comparatively unmodified by weathering. To a striking instance of this, west of Mount Kenya, he gave the name of the Rift Valley, and that term has often been extended, but improperly, to valleys which, like that of the Jordan, would more correctly be called trough-fault valleys.

Displacements along the planes of faults, when they are at all sudden, produce tremors in the crust of the earth, which are sometimes propagated through it to

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[1] *The Great Rift Valley of Central Africa* (1896), p. 220.

very great distances. Such tremors, which may also be connected, though more locally, with volcanic explosions or the struggles of lava to reach the surface, are called earthquakes. They may vary in their intensity from a slight quivering of the ground, like that caused by the passage of a heavy waggon, to a concussion which is sometimes very destructive. Certain regions suffer from such earthquakes more severely than others, and these are observed to be, as a rule, closely connected with regions of folding or faulting. During one of them undulatory movements traverse the ground, in brief but rapid succession; waves, one of which is often formidably great, are started when the shock originates beneath the sea; chasms open in the earth, and landslips may occur; buildings are shattered and thrown down, often with great loss of life. In North America, Charleston and San Francisco have suffered severely more than once, and both in comparatively recent years. On November 1, 1775, the greater part of Lisbon was destroyed, with a loss of more than 30,000 lives. The Calabrian coast, with the immediately adjacent part of Sicily, has several times suffered heavily. In the worst shock of a disturbed period, which lasted from 1783 to 1786, Messina and other towns were shattered, with an estimated loss of about 40,000 persons. The calamities recurred in 1857; and the partial destruction of Messina in Sicily, and Reggio in Calabria, about five o'clock in the morning of December 28, 1908, during which, according to the official estimate, 77,285 persons perished, is still fresh in memory. In the Rann of Cutch, on June 16, 1819, a large area of land sank beneath the sea during an earthquake, while a smaller one was elevated; and in Japan, which might be called a land of earthquakes, one on October 28, 1891, caused a crack to open in the ground which ran for about seventy miles, crossing almost the entire breadth of Nippon, and caused a vertical displacement which in some places amounted to about twenty feet.

It would be easy to multiply examples, but these may suffice to give some idea of the terrible destruction which may be caused by earthquakes. Our own islands have happily been almost immune from serious shocks, probably because the movements caused by folding practically ceased at a fairly distant epoch, and the rocks affected by them are buried in our lowland districts beneath a thick covering of comparatively loose and inelastic materials—which, if the former were shaken, would act like a feather-bed.[1] But where the older rocks come to the surface, as in Scotland, minor shocks are not infrequent, and they occasionally make themselves felt in different parts of England. As a rule only a slight trembling of the ground is perceptible, and that over a comparatively limited area, but now and again some little damage has been done to buildings, such as when the front of Lincoln Cathedral was cracked in the year 1185, and when, in the East Anglian earthquake of April 22, 1884, the cost of repairs amounted to several thousand pounds. The concussions due to the more severe earthquakes are often felt over very large areas of the earth's surface, and can now be detected, where they are far too slight to be otherwise noticed,[2] and the position of the centre of disturbance can even be located, by the aid of delicate recording instruments, called seismometers, which have added greatly to our knowledge of the nature of the movements and have supplied some indirect, but important, evidence in regard to the internal constitution of the globe.

It is very difficult to determine the causes to which these several forms of crust-disturbance are due. More than one explanation has been offered. Some regard them as a consequence of the secular cooling of our planet, which, as already stated, must have formerly been an incandescent mass. The loss of heat by radiation and the consequent contraction of the zone beneath the part which had already become solid would cause

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[1] The Lisbon earthquake was not noticed in England, but the shock was perceived, though but slightly, in Scotland.

[2] It is estimated that 30,000 to 40,000 earthquakes occur annually, the great majority being fortunately harmless.

the latter to wrinkle, like the skin of an apple when it is drying. This contraction might sometimes make a separation between the zone, which was already cold, and that which was still plastic, the consequence of which might be fracture and collapse under the action of gravitation. Others suppose the strain produced by the rotation of the globe acting upon a crust unequal in strength ; while others, assigning the same cause, think it must be attributed to efforts to assume a form of perfect equilibrium. Even if this had ever been attained, either on first cooling or at a subsequent time, the changes which result from denudation and the transference of material from one part to another would soon introduce instability. This explanation is perhaps the one regarded with most favour at the present time, but we may venture to doubt whether this cause, though it must produce some effects, is adequate to account for such foldings so remarkable as those in the Appalachians and the Alps which are believed to indicate that a strip of crust has been reduced in breadth in the one case by 46 miles, in the other by 74. The whole subject, however, together with that of earthquakes, is far too complicated and difficult for discussion in these pages, so that we must be content to leave it without further notice as one of the problems in physical geology concerning which, notwithstanding considerable accessions to knowledge during the last twenty or thirty years, we have still much to learn.

CHAPTER IX

THE LIFE HISTORY OF THE EARTH

The history of living creatures shows a progressive evolution, though races, like individuals, die out. It illustrates the adaptation of forms to their environment, with consequent modification and the destruction of those incapable of further change. The earlier pages of the record are so defective or blurred that they cannot be read. They begin with the Cambrian period, but we can see from some traces, generally obscure, of things that have lived in still older deposits and from the fact that the great divisions of the invertebrata are represented very early in this period, that it must be long subsequent to the beginning of life. In Britain the records of the early Cambrian are scanty, comprising perhaps 200 species, but they are rather fuller in other lands, especially America. Briefly stated, the life of the Cambrian period is mainly made up of brachiopods and trilobites. It also comprises a few lamellibranchs, gastropods, and (in the uppermost division) a cephalopod ; the crinoids or " sea-lilies " and the star-fish already existed. In the Ordovician the trilobites increase in number and diversity ; the other organisms, named above, show a more gradual advance, and the graptolites, animals rather distantly related to the sea-firs (*sertularidæ*) of our coasts, which appeared at the end of the Cambrian, are very abundant and valuable, in consequence of their rather restricted vertical range, for indicating horizons. In the Silurian the trilobites are dwindling, but a peculiar group of rather large crustaceans makes its appearance, of which the living limulus or king-crab is to some extent a survivor. Crinoids, corals, and the molluscs generally are much more largely and often profusely represented, and, rather late in the period, the first vertebrate, a fish, makes its appearance.

Fishes became abundant in the Devonian or Old Red Sandstone,[1] and corals, with different orders of molluscs, are plentiful, but trilobites are steadily declining. In the Carboniferous system, molluscs, both marine and fresh water, are abundant, and the oldest-known land-shells appear ; insects were plentiful, while in beds of the former origin corals, brachiopods, and crinoids are very numerous. Fish often almost swarmed, and a

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[1] Much of the latter is believed to be a fresh-water deposit.

new class of the vertebrates—the amphibians—is rather sparingly represented.

The Permian fauna is not well developed in Britain, owing probably to local peculiarities, but in other countries it indicates an alliance with that of Carboniferous times with forerunners of the coming system, among which a reptile is of special importance. That, the Trias, is also abnormal in Britain, but from other countries we can see that the Palæozoic fauna had almost disappeared and been replaced by that characteristic of the Mesozoic era. Certain cephalopods, which range throughout it, especially those called ammonites, make their appearance; the molluscs and crustaceans are greatly changed, and show more resemblance to those which are now living. Quite late in the Trias the first mammal, small and with some reptilian affinities, has been found. The Jurassic system is rich in life; crinoids on certain horizons, with almost everywhere molluscs of all kinds, especially ammonites, belemnites (a sort of cuttlefish), and brachiopods. Reptiles now become abundant, and several attain to a great size. Some, like the giant Diplodocus, which was about 80 feet in length, were vegetarians; but certain others, not so big, but more active, must have been terrors to all weaker creatures. Mammals, small and feeble, are found, and the first bird, which exhibits characters indicating a descent from reptiles. The Neocomian is often imperfectly represented in England, and its lower part is a fresh-water deposit in the south-east. The fauna bears a general resemblance to that of the Jurassic, with many indications of coming change. In Cretaceous times a great part of Britain was gradually submerged, while the pure-white chalk, characteristic of that period, was deposited. Large reptiles still existed, but are evidently declining, the most remarkable being the Mosasaurus, which sometimes attained a length of 60 feet, and from its rather snake-like form might be taken for the original sea-serpent. Among the molluscs and other invertebrates, the genera characteristic of the Mesozoic era continue, but a change is beginning to be marked. Mammals are still few, but birds are rather commoner, and nearer in structure to living forms, though some of them were armed with teeth.

In England whole pages are torn out of the story-book of life between the end of the Mesozoic and the beginning of the Kainozoic, the first period of which, the Eocene, shows a great change in the fauna. Brachiopods have become scarce; the ammonites and allied chambered cephalopods have disappeared; the gastropods and lamellibranchs mostly belong to existing genera; the great reptiles have died off; birds are commoner, and so are mammals, which rapidly increase in size and variety. They now show signs of a rapid evolution, so that before long large and strange-looking representatives of this class take the place formerly occupied by the great reptiles. New conditions have begun to prevail, and the remainder of the Kainozoic era shows a gradual approach to the forms of life which now occupy the globe; existing genera among the vertebrates and species among the invertebrates gradually making their appearance, while those of older date drop out of the race.

The plant-history of the globe shows a similar progress, but its more marked changes do not altogether synchronise with those among the animals. At first its record is very imperfect. In the Cambrian, remains of plants are few and obscure. They are but little better in the Ordovician, and not common in the Silurian. They cease to be rare in the Devonian, and are, of course, abundant in the Carboniferous, the vegetation of which continued, though with changes, into the Permian. The Palæozoic flora, like its fauna, differs widely from the present one. It is characterised by the absence of dicotyledonous plants and the dominance of ferns, horse-tails, and club-mosses, representatives of the second (*Calamites*) attaining a large size, and those of the third (*Lepidodendron* and *Sigillaria*) taking the place of forest-trees. A few conifers, however, existed, and perhaps may have been more abundant in hilly districts, the flora of which is almost unrepresented. A change sets in with the Mesozoic; the older flora disappears, and one more nearly resembling the present begins, the characteristic of which is the dominance of palms and cycads. Another change is initiated in the Neocomian flora, and that of the Cretaceous assumes an aspect distinctly modern, and the vegetation throughout the Kainozoic era shows an increasingly close approximation to that which is now in existence.

Great changes of climate must have occurred in the Kainozoic era. During the Eocene it was much warmer than now, and towards the middle of this was almost tropical in the south-east of England. Then it became gradually colder, till in the later part of the Pliocene it must have been nearly the same as at the present time. But soon afterwards it became more severe, and in the Glacial Epoch (the beginning of the Pleistocene) the climate of our islands may have been no less severe than we now find in Spitzbergen. But even then there may have been oscillations, as there probably were in the transition to the time when history begins. It is still a moot question when man first appeared in this part of the world. He was certainly here soon after, perhaps during, the Glacial Epoch. Of late years attempts have been made to carry his arrival still farther back, but in this controversy the final verdict may be in favour of the sceptic.

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Chapter II.—On the Age and Figure of the Earth, see *Age of the Earth*, by W. J. Sollas, Secs. I. and II.; also Sir A. Geikie, *Text-Book of Geology* (Books I. and II., Part i., 1903); and articles on the Earth in Lord Kelvin's *Popular Lectures and Addresses* (Vol. ii., " Geology and General Physics ").

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The author in writing the present volume has kept in mind, not students preparing for examinations, but persons of ordinary education who desire to acquire some general knowledge concerning the earth and the processes by which its surface is modified. Should they wish for rather fuller and more formal information they will obtain it in such books as *A Class Book of Geology*, by Sir A. Geikie; *The Student's Lyell*, by J. W. Judd; and *Intermediate Text-Book of Geology*, by C. Lapworth. Much valuable information on the several subjects mentioned in the present book will be found by referring to their special names in *Chambers's Encyclopædia* or in the *Encyclopædia Britannica.*

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