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FROM METEORITE TO MAN:

THE EVOLUTION OF THE EARTH

BY

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INTRODUCTION

THE surface of the earth, in its manifold and ever-varying aspects, presents to a thoughtful observer enigmas as interesting as those of a crossword puzzle. Changes of the surface take place constantly, sometimes slowly under the action of wind, river, and sea; sometimes imperceptibly but irresistibly when blocks of the crust move along old fractures; sometimes swiftly and disastrously when an earthquake devastates a province or snaps submarine cables by the score. The animals and plants that live on the surface present to the inquiring mind fascinating conundrums as to why they are what they are, and why they are where they are. Beneath the earth's surface are collected stores of materials so disposed that they are available as fuels, ores, building stones, and minerals which renew the fertility of the soil; while some common materials have crystallized as gems which are valued because of their industrial uses as well as for their beauty. The varied processes that control the surface features, the development of animals and plants, and the supply of materials indispensable for civilization are intelligible only in view of the past history of the earth.

The contents of this volume were prepared at the invitation of the British Broadcasting Corporation as a series of talks to summarize that history. The series begins with chapters on the Origin of the Earth, as explanatory of the nature and distribution of its materials. The evidence as to the composition of the earth indicates that it consists in the main of a vast ball of iron, alloyed with nickel and other metals, and surrounded by a strong crust which was given off by the metallic mass as a slag that floated to the surface.

How this outer crust has crumbled into fragments under the influence of wind and rivers and the sea, and decayed under the attack of air and water, is told by Professor Watts in his chapters on "The Wear and Tear of the Land" and "History as Written in the Rocks." Such slowly-acting forces would have required æons of time to have given the surface of the earth its present character. A chapter on "The Age of the Earth" shows that even the inconceivable time necessary for these agencies to have done all that is attributed to them can be safely assumed.

The secondary rocks contain the remains of animals and plants which record the evolution of the present inhabitants of the earth from the simpler types of earlier periods, as is explained by Sir Arthur Smith Woodward; while Professor Seward confirms this view by reference to plants, and shows how the former vegetation laid down the seams of coal which are the main source of fuel and power to the industrial nations.

Evidence that there have been great changes in climate is stated by Professor Seward, as plants once lived in areas now too cold for them. He points out that it is easy to overestimate such climatic changes, and that the claim that Greenland was once a tropical country is not proved by the plants, while it is contradicted by fossil animals that lived in Greenland seas during the supposed tropical period. The plants show that the climate was much warmer than it is at present, perhaps from the same causes that Southern Greenland is covered by an ice-sheet, while Norway in the same latitude enjoys temperate conditions, and that the winter climate of New York is much more severe than that on the opposite coast of the Atlantic at Lisbon. Sir A. S. Woodward, in the final chapter, shows that the success of the higher animals and man in the struggle for existence is due mainly to the growth of brain power.

The correspondence that followed the delivery of this series of Broadcast Talks showed the wide interest in these problems, and has led to their publication in a form in which they will be available for reference.

J. W. GREGORY.

June, 1930.

Chapter I

The Earth and its Origin

By Professor J. W. Gregory

WHEN men began to consider carefully the origin of the earth, the first fact that was clearly established was that the interior must be extremely hot. The heat of the water from deep springs and wells and the trying heat in deep mines show that the temperature of the earth increases so rapidly beneath the surface that the middle part must be intensely hot. The hottest body of which we have personal evidence is the sun. Hence it was natural to expect that the sun corresponds in condition with the earth in the earliest stage of its history.

This view was first supported from scientific evidence by the astronomers of the eighteenth century. Their improved telescopes revealed to them among the stars some thin, irregular bodies that look like tiny wisps of cloud. They were called nebulæ, from the Latin word meaning little clouds. The easiest of these nebulæ to observe with the naked eye is the Great Nebula in Orion. To find it, look on a clear moonless night at the three bright stars known as Orion's Belt. Below the star which to an observer in the Northern Hemisphere is the left-hand one of the three is a curved line of three smaller stars. They are known as the Sword of Orion. Look carefully at the middle star of the Sword, and you will notice that it has no sharp edge like the other two, but appears hazy and to have an indefinite, irregular margin. This star is the Great Nebula in Orion. It was discovered by the Dutch astronomer Huyghens in 1656.

The nebulæ are quite transparent, as even small stars can be seen through them; and as they are luminous they were regarded as vast patches of white-hot gas. As they are surrounded by the intense cold of space, their material must be giving off heat; and as cooling causes condensation and shrinkage, the nebulæ should condense into a compact outer layer, while remaining hot, loose, and luminous inside. The Nebular Theory of the Solar System, which was expounded by the distinguished French astronomer Laplace in 1796 and 1824, therefore attributed the origin of the sun and its planets to the condensation of a vast cloud of white-hot gas.

An incandescent mantle ceases to give off light as soon as the supply of heat to it is stopped by turning off the gas or spirit; it at once becomes non-luminous, and if there happens to be a flaw it will crack by the contraction on cooling. The outer surface of a nebula would give off heat most quickly, and thus form by contraction on cooling a denser layer or crust. As the nebula was rotating quickly, this crust might break away from the layer below, which, being hotter, would continue cooling and contracting more than the chilled denser external layer. As the crust tears away from the rest, it would break up into fragments, which, as they would be travelling around the sun in the same path, would in time collect into one mass. It would continue to revolve around the sun, and would thus form a planet.

According to the Nebular Theory, this process has happened eight times during the contraction of the Solar Nebula, and thus the Solar System consists of the central still-gaseous sun, surrounded by eight planets. Each of the planets, as they are rotating, cooling, and contracting, would be subject to the same process, and would give off rings like those that render Saturn the most beautiful of heavenly bodies. These rings would in time condense into moons or satellites.

This theory was delightfully simple and complete, and it fitted in with much evidence as to the behaviour of the Solar System and with fresh discoveries as to the nature of the stars. On the Nebular Theory it would be expected that the sun would be composed of comparatively diffuse material, that the densest planet would be nearest the sun, and that the farther the planets are from the sun the lighter would be their material. The material of the sun weighs only a quarter as much as an equal bulk of the earth. Mercury, the nearest planet to the sun, was regarded as composed of the heaviest material; Venus, which comes next in position, was considered slightly denser than the earth; Mars, which is farther from the sun than the earth, is less dense; and the outer planets consist of material which weighs only from an eighth to a quarter as much as that of the earth.

The theory had as one of its main supports its simple explanation why all the members of the solar system travel nearly in one plane in space, and why they are all travelling around the sun in the same direction. With the sporting instincts of the human race, great is the faith in odds! And they were overwhelmingly in favour of the Nebular Theory. For it was calculated that the odds against a miscellaneous assemblage of as many bodies as the members of the solar system travelling in the same direction would be as

[*By permission of the Mount Wilson Observatory, California.*

FIG. 1.—THE NEBULA IN URSA MAJOR.

10,000,000,000,000,000,000,000,000,000 to 1, that is, as ten thousand million million million millions to one. Even in the most speculative circles that would be counted as a certainty.

It was not till late in the nineteenth century that the theory was seriously questioned. One obvious difficulty was how such tenuous material as that of a nebula could maintain its heat when surrounded by the intense cold of outer space. A human being in a covering of thin muslin would soon perish in an Arctic night by the loss of heat; and a hot gas in space would lose its heat so fast that it would soon become dark and cold, like the dark nebulæ which astronomers have discovered in large numbers in recent years.

Sir Norman Lockyer surmounted this difficulty by the suggestions that the nebulæ consist of swarms of meteorites which are constantly bumping against one another, and that the heat generated by the collisions converts part of the meteorites into vapour, which is so hot as to be luminous. If the collisions in a travelling swarm of meteorites were sufficiently violent and frequent, they would maintain the cloud of incandescent gas which is the visible part of a nebula. This Meteoritic Hypothesis goes a stage farther back than the Nebular Theory. It represents the universe as originally packed with meteorites as crowded as the particles in a cloud of dust. Space was at first a meteoritic "plenum"—a word meaning the opposite of a vacuum. The meteorites are familiar to us as shooting stars, which fly through space in prodigious numbers. They are usually dark, but become visible when they enter the earth's atmosphere and are heated by friction with the air. They may be seen flashing across the sky on any clear moonless night. It is calculated that an observer can then see on an average about eight to ten every hour; hence twenty millions or, according to another opinion, 400 millions of them enter the earth's atmosphere every day. The assemblage of cold solid meteorites into a crowded swarm is facilitated by the fact that many of the meteorites travel around the sun like infinitesimally small planets. They have therefore been called planetesimals. All in one zone would be collected into a swarm, which would contract into a continuous mass and be fused into a solid planet by the heat due to the collisions and pressure.

The Meteoritic Hypothesis made little headway until the Nebular Theory had been shown to be inconsistent with the essential facts.

The Nebular Theory has been generally discarded, and the earth is regarded as formed from a swarm of meteorites which may have arisen from the condensation of matter dragged out of the sun by the attraction of a passing star. The attraction of the moon on the earth pulls the waters of the ocean towards the moon as a tidal wave. The passage of this wave around the earth forms the rise and fall of the tides. A star passing the sun would raise a tidal wave in its surface, and the crest of the wave may have been torn off by the attraction of the star. Such a fragment of the sun may then have condensed into a swarm of meteorites, and they may have collected into a continuous mass which revolves around the sun as a planet.

The meteorites which gave rise to the earth may, however, have been formed by the union of particles of a primeval cosmic dust which, according to some authorities, was universally distributed through space. It is not for geology to decide between the four most plausible theories as to the origin of the meteorites that formed the earth. They may be due to a knot in a consolidating nebula, or may be matter shot out of the sun by an internal explosion, or drawn out of it by the attraction of a passing star, or they may be due to the aggregation of cosmic dust. But the conception that the earth was due to the consolidation of multitudes of meteorites fits in well with the evidence of geology as to the structure of the earth.

Hence the view that the whole solar system has been formed by the condensation of a mass of white-hot gas that once occupied the whole space as far out as the remotest of the sun's planets, is attended by so many difficulties that it is no longer generally accepted. It is more probable that the earth was formed by the collection of immense numbers of the meteorites which are familiar to us as shooting stars. These meteorites were highly heated when they came together, and were thus welded into a continuous mass.

CHAPTER II

What the Earth is Made Of

By Professor J. W. GREGORY

WE saw in the last chapter that the materials of the earth were probably assembled as a swarm of meteorites. Now meteorites are of two chief kinds—metallic meteorites, which consist of iron and nickel, and stony meteorites, which consist of the same materials as compose the rocks of the earth's crust. In museums the iron meteorites far exceed in weight the stony meteorites. The famous meteorite collection in the British Natural History Museum at South Kensington, when the proportion of the two kinds was once determined, contained 12,000 lbs. of iron meteorites and only 900 lbs. of the stony kind. If this proportion represents the distribution of the material in space, the consolidation of a swarm of meteorites would give rise to a body consisting mainly of nickel-iron and a smaller proportion of stony matter. During the consolidation of the meteorites into a continuous mass the material would be melted and the heavier constituents would sink and the lighter float to the surface. Iron ore also consists of a mixture of metallic and stony materials; and when iron ore is smelted the metal sinks to the bottom and the stony material, being lighter, rises to the surface and solidifies there as a slag. While the slag is cooling, it gives off gas which may burn on the surface in jets of flame; and steam is given off and condenses as water. Hence a body formed from a swarm of meteorites should have a great central mass consisting mainly of metals, especially iron and nickel, and an outer crust of lighter stony materials. The moisture from the interior would condense as the water of rivers, lakes, and the sea, and the gases would pass outward and envelop the whole earth as its atmosphere.

The proportion of nickel in the iron meteorites is about the same as is used to harden steel for armour-piercing projectiles. We may, indeed, regard the earth as a huge spherical projectile which is whirling through space. It is composed mainly of iron, and is hardened by its nickel alloy; and it is surrounded by a thin crust of rock which has been separated from the metals within, as slag is separated from the iron when its ore is smelted. That the earth has this structure is proved by various lines of evidence. The fact that the main mass of the earth consists of some metal about as heavy as iron was proved when the earth was weighed. Isaac Newton calculated that the earth weighs from five to six times as much as an equal volume of water. This conclusion appeared startling, as the upper rocks of the earth's crust weigh only two and a half times their bulk of water; so that, according to Newton, the earth weighs twice as much as it would do if it were composed entirely of the rocks that form the surface. Newton's conclusion was proved about 1774, when the earth was first weighed. The mountain of Schichallion, in Perthshire, was used as a weight and the attraction of the plumb-line towards it showed how many times the earth is heavier than the mountain. The calculations indicated that the earth is a little lighter than Newton's estimate, which is, however, the more correct, for the earth weighs between 5·6 and 5·8 times as much as an equal volume of water. The rocks near the earth's surface weigh from about 2·5 to three times as heavy as water. Hence the earth as a whole, owing to its high content of metals, is twice as heavy as its crust.

This conclusion has been confirmed by the study of earthquakes. An earthquake is a wave that travels through the earth, as a wave travels outward through a pool of water, from the point where a stone falls into it. A great volcanic explosion sometimes shakes the whole earth, and its surface is traversed by earth-waves.

The time at which an earthquake wave reaches various localities is marked by recording instruments. John Milne, the founder of the modern study of earthquakes, discovered that the waves often travel faster than was expected from their rate near the place whence they started. Their journey could be shortened by going in a straight line through the earth instead of along the curve at the surface; but their increase of speed is far greater than could be thus explained. Milne recognized that if an earthquake wave on its course goes more than forty-five miles deep its speed is greatly increased (*see*

Fig. 2). He therefore concluded that at about that depth there is a great change in the composition of the earth. Below that depth the earthquake wave enters material through which it travels much faster than through the crust. Hence Milne concluded that the rocky crust of the earth is about forty-five miles thick, and that the crust rests upon a metallic globe composed of iron and nickel.

This conclusion is supported by radioactivity. Certain substances such as radium give off rays. The rocks of the earth's crust have this property to some extent. But the earth's radioactivity is so feeble that it can be explained by there being no radioactive material below about forty miles

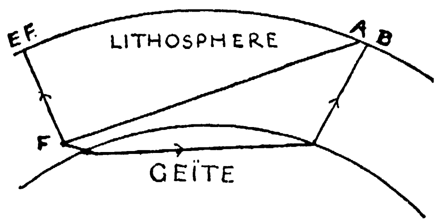


Fig. 2.—Earthquake Tracks.

F is the place of origin of a set of earthquake waves. They will reach the surface of the earth at A later than they reach it at B, for, though the line from F to B is longer than from F to A, FB passes through the Geite, the metallic mass, forty-five miles below the surface of the earth.

deep. The material of the nickel-iron meteorites is one of the few substances that are not radioactive; this fact strengthened the belief that a rocky crust about forty-five miles thick rests upon an internal mass of non-radioactive nickel-iron.

The evidence of earthquakes has proved further that the central core of the earth is in a different condition from the shell around it. Earthquake waves are of three kinds—waves of compression or push-waves, waves of distortion or shake-waves, and the large free waves which do all the damage on the surface (*see* Fig. 3). Push-waves, like those of sound, can travel through solids, liquids, or gases; but shake-waves are transmitted only by solids. Hence, as the central part of the earth does not transmit shake-waves, its material must be either gaseous or liquid. It is more likely to be liquid than gaseous, and the middle of the earth, to the extent of about two-fifths of the diameter, probably consists of a heavy liquid. The old view that the earth consists of a liquid interior surrounded by a solid shell is now justified.

The Meteoritic Theory best agrees with the geological conditions and history of the earth. According to the Nebular Theory, a very high temperature would be expected in the centre of the earth. The temperature rises downward from the surface, as is only too well known to miners. The rate of increase varies in different parts of the earth; but the average has been often taken as a rise of one degree F. for every fifty-three feet in depth. If that rate were maintained the temperature

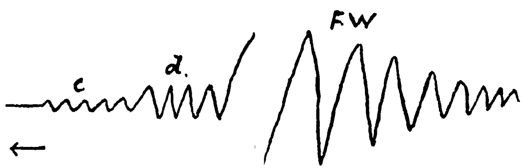


FIG. 3.—WAVES IN AN EARTHQUAKE.

c, preliminary tremors of waves of compression; d, waves of distortion; FW, the free waves of the main shock.

would rise 100° F. for every mile of descent, and the centre of the earth would be at a temperature of about 400,000° F.

There is no geological evidence of any such high temperatures within the earth. It is therefore probable that the rate of increase of temperature which is observed at the surface becomes slower on passing away from the cooling surface of the earth. At the base of the crust the temperature may not be above 2000° F. As nickel-iron is a good conductor of heat, the temperature may be fairly uniform throughout the deeper metallic mass. The temperature in the hottest part of it may not be more than the moderate amount of a few thousand degrees. No rocks on the earth show the effects of temperature of more than 3000° F.; and that heat can be explained as due to the collision and weight of the consolidating meteorites and the pressure of the contracting globe.

Further, if the earth has been formed from an incandescent nebula which has been slowly cooling, its climate should have gradually become cooler. Occasional fluctuations might occur as the result of geographical changes; but, omitting temporary variations, the climate should show a progressive change from super-tropical heat, when the earth was young, to its present moderate temperature. The fact that glaciers in the Great Ice Age covered parts of Britain where forests of tropical luxuriance had grown in the Coal Period was regarded as one result of this slow refrigeration. The distribution of coal was regarded by some geologists as giving proof that at one time the whole earth had a uniform tropical climate. It was therefore a great surprise when it was discovered that glaciers existed upon the earth, and even in the tropics, in the very first chapters of geological history. In China, west of the city of Hankow, where the summer climate is of tropical warmth, and especially unpleasant owing to the combined heat and moisture, a series of ancient boulder clays show unmistakably the former action of ice. The hills of South Australia, from behind Adelaide into the tropics near Lake Eyre, contain a long band of glacial deposits; they date either from the earliest period which in the British Isles has yielded definite fossils, or from only slightly earlier. The nature of the ancient glacial deposits of South Australia shows that they were not formed on a high mountain range, but were laid down on lowland and probably in part in the sea. Hence at the beginning of the geological record glaciers existed on the earth in places too warm for them now. This does not indicate that the climate of the whole earth was then colder than now. The glaciers were probably local and due to a different distribution of land and water, causing a heavy snowfall in places that now have a warm climate. While South Australia and Central China were colder than they are to-day, other countries were warmer. The temperature of the earth as a whole was probably much the same as it is now. Though there have been great local variations of climate, there is no evidence of any progressive cooling of the earth's surface since it has been the abode of life.

This conclusion is more in accordance with the Meteoritic than with the Nebular Theory.

Chapter III

The Age of the Earth

By Professor J. W. Gregory

THE theory that the earth has been moulded by the forces that are working to-day, and by those forces working at their present rate, has been rejected on the ground that it demands an impossible length of time.

The question of the age of the earth is fundamental to the study of the evolution of the earth and the development of life. Let us then consider what are the grounds for the view that the earth has had a comparatively short life, and whether these grounds are valid. In efforts to discover the age of the earth, six chief methods have been used: (1) estimate of the duration of the heat supply from the sun; (2) determination of the date at which the surface of the earth had become sufficiently cool to be possible as the abode of life; (3) the use of the rocks on the earth's crust as a clock by which to measure the time occupied in their formation; (4) inferences from the saltness of the sea; (5) the rate at which lead has been formed by the decomposition of uranium; (6) various astronomical methods, including the shape of the orbit of the planet Mercury and the relations of the earth and the moon. I think we shall find that all reliable methods prove that the earth is of an inconceivable antiquity, and that geologists and biologists need not be in any way embarrassed by lack of time. They can have as much as they want.

As to the age of the earth, there have been two conflicting trends of opinion. According to the religions of the Near East, the past of the earth has been short and of about the same length as that of man. Those of the Far East, on the contrary, have held that the duration of the world has been so long that it may be regarded as eternal. Modern scientific opinion has been divided into two corresponding schools. Geologists were convinced of the immense antiquity of the earth by the slowness of the processes that mould its surface. Some of these claims, it is true, were based on exaggerated estimates. For example, Darwin considered that it might have taken 300 million years to make the valleys near his home in Kent, and his contemporary Jukes declared that the actual time may have been a hundred times longer. According to Jukes's view, 30,000 million years were required to erode a series of minor valleys. These estimates were based on the rate at which the valleys are being enlarged during their present mature condition; whereas most of the excavation would have been done under different conditions when the rate of erosion must have been rapid. Jukes's estimate was as reasonable as the calculation of the time that would be taken by a letter to reach its destination, based on the distance the pillar-box in which it was posted had moved in the course of an hour.

Geologists early recognized that the processes which make rocks are so slow that the deposition of the sedimentary rocks, of which the layers amount to from seventy to eighty miles in thickness, required many hundreds of millions of years. The biologists supported the geologists by demanding vast lengths of time to allow of the development of the existing animals and plants by evolution from the first forms of life.

The doctrines that the earth has been the abode of life and that the conditions on its surface have been uniform for æons of time were first seriously challenged by Lord Kelvin. He claimed that the sources of heat and energy in the Solar System are limited in amount, and that the sun cannot have given off heat at the present rate for more than a few tens of millions of years. This view he first put forward in 1860 on the basis of the rate of cooling of the sun, which he said must become appreciably cooler every million years. Two years later he reinforced this conclusion by the loss of heat from the interior of the earth; he concluded therefrom that the earth cannot have been inhabited for more than about twenty-eight million years. That argument rests on the assumption that the temperature within the earth rises uniformly from the surface to the centre; whereas we have already seen that the rise of underground temperature is slower in the lower part of the crust than near the surface, and that the interior below the crust probably has a fairly uniform temperature. By reasonable modifications to allow for that fact, Lord Kelvin's figure for the age of the earth (at that time 100 million years) should be multiplied by 290, giving the earth an age of nearly 30,000 million years. Lord Kelvin admitted in the later discussion that he must allow an age of 4000 million years as possible; and his critics raised that figure to 10,000 million years. The extreme difference between these estimates shows that this line of enquiry gives no indication of either the probable or possible age of life on the earth.

A second argument was based on the heat supply from the sun. According to Helmholtz, the heat of the sun is produced by the contraction of its mass. This cause, according to the knowledge at that time, only accounted for the maintenance of the sun's heat for a period of from twenty million to 100 million years; a more precise later estimate gave the maximum as forty-six million years. It is, however, probable that the heat of the sun is produced by other causes. It may be given off when atoms are broken up or when matter is annihilated on its conversion into energy; this latter process is such an inexhaustible source of heat and energy that, according to Sir James Jeans, the Solar System may have lasted for eight million million years.

The use of sedimentary rocks as a clock for the measurement of geological time has long promised a useful basis for calculation. Sir Archibald Geikie in 1892 estimated the thickness of these rocks as 100,000 feet, and from the rate at which material becomes available for them by the wearing away of the land, he considered that the deposition of these rocks might have been effected in seventy-three million years, although it might have required 680 millions; he took 400 million years as a probable estimate. The thickness of the sedimentary rocks is, however, far greater than was known at the time of that calculation. The fossiliferous portion of them is at least 350,000 feet thick, and the earlier sediments without fossils were probably as thick. Hence, these sedimentary rocks may be seven times as thick as the amount upon which Sir Archibald Geikie's calculation was based.

The rate of formation of such rocks varies greatly, but is usually very slow. Nile mud is laid down in Egypt at the rate of one foot in 350 years in some places and of one foot in 500 years in others; and a foot of this material makes only a few inches of rock. In other places the accumulation is faster, being three inches or a foot a year. Such rapid accumulation is local, and the Nile rate is a better guide. And if the 350,000 feet of fossiliferous beds were deposited at the rate of one foot in 500 years, their formation would have required 175 million years, and, in addition, an equal period would have been required for the earlier sediments. One foot in 500 years is not unduly slow. For some authorities have assumed rates for shale and limestone which would require the time to be multiplied for part ten-fold and for part thirty-fold.

In opposition to these high estimates, Professor Tait, of Edinburgh, claimed that the age of the earth was no more than ten million years. In response to such claims, geologists adopted two attitudes. One was a contemptuous *reductio ad absurdum*. It was pointed out that Tait had omitted various factors, and with due allowance for them the evolution of the world since life began took three million years less than no time at all. Other geologists and Russel Wallace were prepared to admit that the geological evidence was consistent with the duration of the earth for only a few million years. One American geologist thought Lord Kelvin's brief estimates far too long, and that the whole of the sedimentary rocks could have accumulated in three million years. This view met the prompt reply from another American that rock deposition is so slow that the age of the earth must be 6,000 million years.

Another argument by which some geologists have supported the relatively short age of the world is based on the saltness of the sea. The sea is great, says a Chinese proverb, because it does not reject the tiniest rivulet. The sea is salt because every river and rivulet carries into it some salt which is left there when water is evaporated from the surface to form clouds and rain. Estimates based on the saltness of the sea rest on the assumption that the sea water was originally fresh and has been rendered salt by material carried into it by rivers from the land. If this transfer of salt to the sea has been at a constant rate throughout geological time, and we make a few other equally improbable assumptions, the age of the ocean may be determined by dividing the amount of salt in the sea by the amount added to it each year. According to one calculation, there are 12,600 billion tons of salt in the sea, and the rivers carry down to it 156 million tons a year, and so could have given the sea all its salt in 81 million years. The method, however, is attended by so many uncertainties that no reliance can be placed upon the results.

In recent years the most convincing evidence of the longevity of the world has come from the physicists. The most precise dates are given by radioactivity. The metal uranium is constantly breaking up into different materials including the gas helium and one form of the metal lead. The rate at which uranium produces helium has been measured by Lord Rayleigh, and from the amount of lead in a rock its age can be determined. Helium, being a gas, readily escapes, and the amount of it left in the rock may be an unknown proportion of the amount that has been produced. Lead, however, being a stable material provides a more accurate measure of the full age of the mineral. On the base of this uranium-helium-lead series, the ages of various rocks have been calculated, and a list by Prof. Holmes in his *Age of the Earth*, p. 73 (Benn, 6*d*.), shows that the London clay was formed 50 to 60 million years ago, our seams of coal 250 million years ago, and the oldest rocks, 1260 million years ago.

Astronomical investigations yield still longer periods. Many methods have been devised for determining the age of the earth on astronomical grounds. Thus, the planet Mercury travels around the sun on a path which differs more from a circle than the path of the earth. The orbit of Mercury is tending to become circular and from its shape the age of Mercury is calculated as between a thousand and ten thousand million years. The moon supplies another test. It produces the tides on the sea which act as a brake on the earth's rotation; and from its present rate the moon has been acting as a brake for some period between one thousand and twenty thousand million years. The astronomical results generally indicate an age of the Solar System of between eight thousand and fifteen thousand millions of years. So far from astronomers and physicists telling geologists and biologists that they cannot have as much time as their interpretation of the development of the earth requires, physical science now allows natural science more time than it knows what to do with. Sir James Jeans's figure of eight million million years is an amount of time which a simple geologist cannot distinguish from eternity.

Cowper in his poem ridiculed the folly of geologists who had the presumption to conclude regarding the earth:

> That He who made it and reveal'd its date
> To Moses was mistaken in its age.

The evidence is now overwhelming that the age believed by Cowper was a mistake, and Lord Kelvin and Russel Wallace are not the only high authorities who were mistaken in assigning a short existence to our venerable world.

CHAPTER IV

The Continents and their Foundations

By Professor W. W. WATTS

GEOLOGICAL science in its stricter sense, and by its own methods of reasoning, is able to reach back only to the later parts of the long history of the earth. And on looking back our view becomes less and less clear as the time grows more remote, until at last only its more pronounced features remain visible to us.

Nevertheless, within this time a long series of events took place, influencing the landscape, climate, and general physical features of the earth's surface, and its plants and animals. These events throw light on the nature of the earth and its inhabitants at the present day, which cannot be explained unless their history is known.

Geological knowledge is obtained from the close study of the surface features of the earth, and of the structure and composition of the crust of the earth, that part of it which is accessible to our direct observation in cuttings, quarries, and mines, or to inferences reasoned out from such direct observation.

The study of a map of the world brings out the contrast between the great land masses, or continents, with their peninsulas and islands and land-locked seas, occupying more than a quarter of the earth's surface, and the great oceans covering the rest.

Relief maps of the continents show that they are made of three main elements: plains, plateaux or elevated plains, and mountain ranges reaching a maximum of five miles in height. Similar relief maps of the oceans reveal the reverse of this picture. The plains are continued as shallow margins, of varying width, which descend abruptly to the wide, flat, or gently undulating sea-beds, and these in places descend to depths of five or six miles.

The continents are rarely symmetrical in their relief or elevations. The chief mountain ranges are usually near one margin : west, or Pacific, in America ; southerly, or Indian, in Asia. Sometimes mountain ranges on the continent may be continued from the peninsulas into lines of mountainous islands, as in the peninsulas and "festoon" islands off the eastern coast of Asia or in the East or West Indies.

That side of a continent which has a gentle gradient is called its "slope," that of steep gradient the "counterslope." Down the slope run the greater rivers to the Atlantic and Arctic Oceans; down the counterslope the more rapid torrential rivers to the Pacific and Indian Oceans.

The slopes slip down into the gentle grades of the ocean bed, as in the Atlantic and Arctic; the ocean floor continues the abrupt descent of the counterslope, and here are situated the great ocean deeps, as in the eastern Pacific and off Japan and the other "festoon" islands. The higher the mountain system the deeper is its contrasting ocean hollow.

Depth charts show that the shallow margins of the oceans are really parts of the continents, being the foundations on which the continents are built, but at present drowned under water that may be as much as 100 fathoms deep. The steep slopes between them and the ocean flats define the continental features, marking the contrast between the upstanding and the depressed parts of the earth's crust. It is a curious fact that if the oceans subsided to a level half-way down the continental margins, the amount of water filling the ocean hollows would about equal in bulk the land that would then emerge above that level. That is to say, this level represents the mean level of the land of the globe.

If the margin of the "continental shelf"—that is, the 100-fathom contour—be taken as the true edge of the continents, as opposed to the oceanic areas, the shape of the continents would be for the most part only slightly altered, merely a narrow strip of land being added to them. But in some places broad strips would become unsubmerged. One would unite Asia with North America, another Australia with the islands to the north-west; and the British Isles would be joined to Europe.

The shallow marginal seas which drown the edges of the continents are called "epicontinental seas," and bracketed with the mediterranean type of seas, such as the Mediterranean itself, the Baltic, and the Black Sea, and with the greater inland seas like the Caspian. These seas are of much interest to geologists, as they receive most of the sediments worn off the land by rivers and by the sea from its coasts. The sediments are destined to become rocks like those of which the main parts of the continents are built.

If continental rocks have been formed under the sea the epicontinental seas must have been elevated to form land. We find evidence of earth-movement of this character all over the world. Sometimes it is local, as in the Bay of Baiæ, where the pillars of a building erected by the Romans at the beginning of the Christian Era are still standing (Fig. 4). The pillars have been bored by shell-fish such as live in the Mediterranean, and some of the shells are still in the holes. The highest holes are now about 21 feet above the level of the sea. The building was therefore depressed to this extent and re-elevated 21 feet. The elevation was completed by the beginning of the sixteenth century, and since then the ground has again been slowly subsiding. Here the land near a group of volcanoes has oscillated locally.

But there are movements on a far larger scale. Much of Greenland is now measurably subsiding. Along the coasts of Lancashire and Cheshire relics of forests now submerged at high tide again prove subsidence. On the other hand, large areas of Norway, Sweden, and the north Baltic shores prove to be slowly rising. Further, the occurrence of lines of beach pebbles, banked against sea-worn cliffs, in Sweden and Norway, at heights up to several hundred feet, proves that the uplift has been going on for long ages.

At some places the subsidence is directly related to the loading of the earth-crust. The silt deposited by the Ganges and Brahmaputra in their delta is causing it to sink slowly. A boring drilled through the deposit passed through a layer of peat 10 feet below sea level and another 370 feet lower separated by silt deposits. Each layer must have been formed at, or just above, the level of the sea, and hence the delta must have slowly sunk during the deposition to the extent of 380 feet at least.

The rise of Scandinavia took place when the great mass of ice of the Glacial Epoch was melting away, and northern Europe was gradually relieved of its enormous weight.

To explain this sensitive response to loading and unloading, the continents are supposed to rest on a plastic substratum, capable of yielding slowly under pressure. They would thus behave like ice floating on water, and as the greater part of an iceberg is under water and a much smaller proportion above it, so the continents must have deep roots in the plastic substratum. When they sink under a load they must press out the yielding substratum to gain room, and, on the other hand, the substratum material must move under the continents

FIG. 4.—THE REMAINS OF A ROMAN BUILDING NEAR NAPLES.

when they are lightened in any way. This flux and reflux will cause strain, distortion, and earth-movement, at the continental margins, and it is here that earthquake shocks, volcanoes, and mountain ranges made of disturbed and broken rocks are most frequent.

The great mountain ranges of the world are associated with what are still, or once were, the margins of continents, or areas of sea-bed that were loaded and filled up with sediment. They swing in long, curved lines in such directions as to constitute the framework of the continents. This is well seen in the Rocky Mountains, the Andes, the coastal ranges, the Appalachians, and the Brazilian Highlands of the New World, in the great Alpine-Himalayan range of the Old World, and in the "festoon" islands, a chain of rising and embryo mountains bordering eastern Asia. While the Pacific Ocean is bordered by ranges running parallel to its margin, in the Atlantic the ranges strike the coast at a high angle and are broken off abruptly at the margin. This fact implies a great difference in the origin and history of the two oceans.

Mountain ranges are of varying ages, the newest being the highest and most impressive. The older have long been decaying away like those around Hudson Bay, or in North Scotland, or Finland. In all of them, old or new, great thicknesses of rock were first formed, partly in the sea, partly by volcanoes. Then by enormous lateral pressure the rocks have been bent and crumpled, thrown into waves, thrust together, and forced into a width varying from one-fourth to one-eighth of that they formerly occupied. The rock-waves have overtopped and broken almost into "spray," like waves at sea; and just as an occasional water-wave will suddenly rush much farther up the strand than those before and after it, so some of the rock-waves have rushed forward, often many miles, as thin rock sheets.

The intense complexity of mountain structure and its resemblance to the breaking of water-waves suggests an analogous cause. In water-waves the cause is external, and is the influence of winds and tides. Is it possible that some attracting and dragging force, external to the earth, has been similarly responsible for the production of rock-waves, acting with special intensity during the chief mountain-building periods that the earth has been through?

Leaving causes aside, we can but admit the periodic operation of such compressive forces as are producing embryo chains like those now rising on the ocean margins in the "festoon" islands of Asia. And when it is recognized that the ranges, lofty as they are, are floating on a plastic substratum, and must therefore have roots submerged in it far greater than the visible part which rises into the air, it will be realized how vast must be the forces responsible.

Under the pressure to which they have been subjected, even the most rigid rocks have been bent, stretched, and moulded, as though made of wax. But in the breaking of the waves the rock-sheets have in places been smashed and shattered. This manifests itself in earthquake shocks, which are associated with mountain ranges and the unstable ocean margins.

Other associates of mountain ranges and lines of instability and weakness are volcanoes, built out of rock fragments ejected by steam from the interior, or of molten rock poured out in the form of lavas. The lava is derived in part from the plastic substratum, which may be liquid or capable of becoming liquid wherever and whenever the vertical pressure on it is relieved.

Small volcanoes like Stromboli have frequent eruptions in which steam contained in the lava escapes with violence, blowing it into froth, dispersing the froth in the air in the form of ashes and dust, and helping to bring the lava to the surface so that it pours down the side of the cone.

In the large European volcanoes, such as Vesuvius and Etna, eruptions are not frequent and the steam attains highly dangerous pressures, shattering parts of the cone, blowing the fragments to a great height into the air so as to darken the sun and cover many square miles of country, injecting the lava into cracks and weak places in the cone or the rocks on which it is built, and ejecting lava streams.

The most violent eruptions on record are associated with islands of "festoon" type. The eruption of Mount Pelée in the West Indies in 1902 brought up a lava so charged with steam that it exploded into red hot dust, which rolled down the mountain, destroyed the town in its path, and killed all the people who inhaled it. The residual lava was thrust up and out of the crater and solidified as the "Spine of Mt. Pelée."

The island of Krakatao in Sunda Strait, between Java and Sumatra, had in 1883 so violent an eruption that three-quarters of it was blown into dust by the escaping steam, and every living thing on it destroyed. The explosion was heard 3000 miles off, caused a sea-wave which reached Aden and Port Elizabeth, and an air-wave that travelled three times around the world. The fine dust was blown so high that it was caught by the upper currents of the atmosphere and carried many times round the world, and produced the marvellous red sunsets that lasted for a year (1883–4), and were seen all over the world. They were undoubtedly caused by the finest of the dust remaining thus long suspended in the air.

Chapter V

The Wear and Tear of the Land

By Professor W. W. Watts

THE water of the globe is the enemy of the land, and is always at work trying to cut it down and thus destroy the outstanding relief of the land and fill up the hollows with its debris. This is work, however, that takes time, and in the process there is plenty of opportunity for selection. To this selective sculpture much of the beauty in form of hill and valley, of ridge and peak, of cliff and cave is due.

The great Falls of Niagara plunge 165 feet over a shelf of limestone, into a deep pool excavated by the water from softer shale that underlies it. The tremendous weight of the water, the air current carried by it, the spray, and the stones brought over by the water, all wear away the soft shale, undermining the limestone to such an extent that it is possible to walk under the cornice thus made, and under the water of the fall in what, for good reason, is called the " Cave of the Winds." Whenever the under-cutting has gone far enough, great masses of the limestone break away, and the fall retreats a little way higher up the stream.

This rapid cutting back is just what is required to have produced the steep-sided gorge below the falls, which is in such sharp contrast to the more open valley leading out of Lake Erie. The gorge is seven miles down to Queenston, being cut in a flat plateau of limestone underlain by the shale, both rocks ending here in a cliff which must have been the original site of the falls. Sir Charles Lyell estimated the rate of retreat to be about one foot a year, and this gives 35,000 years for the cutting of the gorge from Queenston Heights to the present site of the falls if the rate of cutting has been uniform in the past.

At the Victoria Falls the River Zambezi has discovered a system of cracks in the rocks, and it similarly plunges with vast power into the abyss it has excavated. It had similarly retreated up its valley, and proof of this is given by the tributaries below the falls. As the falls retreated past the mouth of one tributary after another each one fell from its original level into the gorge newly made across it. So they started waterfalls of their own, each one retreating and cutting a tributary gorge. In the lower tributaries the falls are much higher up than in the upper ones, because the retreating time has been longer.

But rivers cut downward as well as backward, and this vertical cutting is the more usual function of swift rivers. Nowhere is this more admirably seen than in the great gorge, or "Grand Canyon," of the Colorado River in Arizona, a mile deep and with sides in the main vertical.

Rivers in performing this work are the servants of gravitation, to which their flow is due; and they are helped by gravitation manifested in other ways. The steep slopes of the valley sides are liable to break away as falls or even landslips. Frost, too, helps to break the rocks down. The water which trickles into the cracks of rocks expands on freezing and wedges them apart, the sharp-edged fragments littering the slopes below the cliffs as "screes." These are continually slipping downhill and feeding into the streams, which, in turn, pick their fragments up and carry them downstream.

Then there is the action of rain. Rain-water dissolves carbonic acid gas from the air, and with its aid can rot away most rocks by removing any soluble ingredient, whether the cement that binds the particles of the rock together, or the more soluble of the particles themselves. This soluble part is carried to the streams in invisible solution. The insoluble residue is left behind in a rotten or disintegrated condition, and is easily washed off by rain, by the minute rills into which rain gathers, or by winds in dry times or arid climates.

All the debris thus gained is swept along by the river, the main function of which is to transport its load down its course and to keep open the slopes at the side of its valley so that the work of rain, frost, and wind may go forward unchecked. River-water thus contains three main things: matter in invisible solution, fine sand and mud in suspension, and stones of various sizes rolled or jumped along the bed of the river. The last are mainly responsible for carving out and deepening the river-bed.

It is the frost work that is mainly responsible for the characters of rock cliffs and crags, and for the sharp peaks and ridges of mountains. Examination shows that these are usually bounded by the cracks, joints, or other natural structures that traverse all rocks. It is because water freezes in such cracks again and again that these structures guide the outlines and characteristics of mountain form. The harder and better jointed the rocks, the finer the rock scenery.

But not all mountains are craggy nor are all valleys gorges. A typical river begins with innumerable tributary torrents rushing down steep rocky mountain slopes. The slopes become gentler as we follow downstream, the bare rocks being increasingly covered with greater and greater thickness of soil. Does wear and tear proceed in these circumstances too?

The mineral ingredients of the soil and the coarser material under it that is called the sub-soil are being derived from the live rock mainly by the operation of frost and rain. These break the rock into fragments, break them into smaller pieces, rot away their crust into sand and clay, and slowly prepare a soil in which plants can root and grow. Further rotting is brought about by vegetation and the acids of its decomposition. Thus the soil tends to grow deeper. But this is prevented if the soil lies on a slope such as a valley side. Here it is continually crawling downwards. Puddling by rain, expansion and contraction on wetting and drying or from heat and cold, the growth and decay of tree or grass-roots, the burrowing and excavation of rabbits or moles, even of ants and worms, and the eventual collapse of the holes—all help the soil on its downward path, which leads always to the river. Into that it is being fed continually or falls periodically, and is swept on. Thus under its mantle of soil the rocks of the landscape are slowly melting away, possibly as fast as among the bare, exposed rocks of the mountain slopes; but the process is harder to watch and measure because it is carried on under the cloak of soil.

But we have only to measure the load that a river is carrying at different parts of its course, to find that it steadily increases downstream, so long as its velocity is maintained. Thus the load the Mississippi River carries to the Gulf of Mexico in the form of sand and mud amounts to 1/20 of a cubic mile annually. If this could be spread over the whole area of the Mississippi basin from which it came and compacted into rock, it would form a coating 1/6000 part of a foot thick over the 1,125,000 square miles of the basin. In other words, that part of the American Continent is being lowered on an average one foot in 6000 years. This is 1000 feet in six million years, as long as the Continent can last, because it is about 1000 feet in average height, unless elevation occurs.

There is one special form of denudation which must be

[*Aerofilms, Ltd.*

FIG. 5.—ONE OF THE GREAT ALPINE GLACIERS.

treated separately—that of water in its solid form. At high altitudes and latitudes the water falls as snow, which piles up in great sheets on cold and lofty land. They are drained by ice-rivers such as the glaciers of the Alps, of the fiords of Norway and Greenland, or the ice sheets of the Antarctic Continent. If water in the liquid state can effect so much erosion it will evidently do much more in the solid form. The glaciers gather debris from the disintegration of the sides of their valleys, and carry it down on their surfaces as "moraines." Some of it falls into the cracks and crevasses, is frozen into the base of the ice, and is then scrubbed by it into the floor of the valley. Thus the valleys are worn down, grooved, smoothed, and polished by the debris, and that in its turn is smoothed and scratched, and in this condition is dumped, or passed to the river into which some glaciers melt, or into the sea, accompanied by immense quantities of mud or rock-flour ground down by the friction of the carried stones on the glacier bed.

In still one other form does water erode the land, this time the edge of it. On the sea coasts storm-waves come thundering against the cliffs with a weight of three or four tons on a square foot. They hurl boulders and stones on the rocky shores, smashing them to bits like artillery.

So the waves are continually mowing down the edge of the land, and some parts of the English coast are losing one or two yards annually. There are records of many villages and towns the sites of which are lost in the North Sea. It is the soft rocks which suffer most, hard rocks being at first the enemy, by providing shingle to batter the cliffs with. Later they form breakwaters and groins on which the energy of the sea spends itself, and until they are destroyed they protect the softer rocks.

Marine denudation appears to be about as efficient in eroding the edge of the land as the rivers and their assistants in wearing away the surface. Thus the total rate of land loss must be about twice as fast as that calculated from the rate of the rivers.

The final effect of the sea's work would be to sweep away all the land, leaving nothing but that below the deepest level at which its action is felt. Thus it will reduce the land to a submarine plain, and this is called a "plain of marine denudation." While the ultimate result of surface action is all but a plain, that of the sea is an absolute plain. When either has been produced, the "cycle of denudation" is finished.

If, however, a plain of either sort were uplifted or if the sea were lowered, life and activity would begin again. Rivers would flow, valleys would be cut, the land between them would stand out as plateaux, which would be narrowed into isolated hills, the sea would again cut into the margin, and a new series of landscapes would be created.

CHAPTER VI

History as Written in the Rocks

By Professor W. W. WATTS

ALTHOUGH parts of the continents are made of rock coming from the interior of the earth, intruding into the crust, and sometimes finding issue in volcanoes, those rocks which are commonest in Britain, and which make up the chief part of the visible crust, are stratified—that is, they lie in parallel sheets one above another. Sometimes they are horizontal, more often they are inclined and thrown into waves, sometimes highly disturbed, as in the past and present mountain ranges. They were formed as sediments, mainly under water.

When the speed of running water slackens down, its carrying power quickly falls off, and some of its load of debris must be dropped. The coarser material sinks quickly, the finer may be swept into deeper water before reaching the bottom, as it falls more slowly and has farther to sink.

Deposition may also occur on the land itself, for instance when a heavily loaded river slackens down in its lower reaches. Here it will deposit pebbles and gravel, while it meanders about the central line of its valley. Again, when it floods its valley or plain it leaves behind some of the sand, silt, or mud that it carries, as a coating on the ground. Deposit also occurs when mountain torrents slow down on reaching an open valley or flatter ground. Lakes and their deposits occur in many valleys. There are some rivers in dry climates which never reach the sea, and all that they carry remains on the land. The areas they reach are generally deserts, and deposits in them have special characters of their own. Again, deposit will occur at the end of a glacier, where the ice melts, dropping some of its ice-scratched stones and rock-flour in "terminal moraines." But all deposit formed on land is ephemeral, and liable to be destroyed and swept off to sea to join the rest.

If the sea is quiet and tideless, the debris is not carried far, and will form a delta. On the other hand, if there are strong currents, the material, and especially the finer part of it, will be caught and swept far over the continental shelves, while it is slowly sinking through the water, and it may even reach the steep slopes bordering these shelves before it all finds rest.

Thus the sea margins become bordered with a belt of coarse deposits, mainly water-worn shingle, a broader belt of sand passing out into silt—that is, finer rock-waste—and a still wider belt of the finest waste, mud or clay. Now the majority of the bedded rocks resemble one or other of these classes of sediment. There are conglomerates, made of pebbles of varying sizes; sandstones, made of sand grains cemented together; mudstones and shales, made of mud and clay more or less consolidated. Further, one of these classes of rock often passes laterally into another, the passage of fine into coarse being in the direction of the shore at the time the rock was forming, just as with modern sediments.

The deposit of a month or a year, spread evenly over the nearly flat sea-bed, will form a thin coating like a coat of paint, and successive coats will be laid down month after month or year after year, giving the deposit a banded or "laminated" character. Precisely similar lamination occurs in shales, mudstones, and some sandstones, the finer-grained stratified rocks.

There will also fall on to the sea-bed—that is, on the surface of a lamina—the remains of dead animals and plants that either lived in the water or were washed off the land; and their less perishable parts will remain and be buried by the silt or mud forming the next lamina. Precisely similar relics are found on splitting open shales or sandstones along their lamination planes. They are the "fossils" of the rocks.

Farther out the amount of mud and silt available becomes so small, in comparison with the remains of organisms, that a region is reached, beyond the "mud-line," where the sea-bed receives and retains nothing but the hard parts of organisms. In precisely the same way we pass through shales and sedimentary rocks rich in organic remains into pure limestones, or into other rocks practically devoid of mechanically borne detritus and wholly made of the remains of organisms—the "organic rocks."

The lamination is most even and regular in the finer-grained sediments. The finer-grained rocks generally best show the lamination. Coarse material is dumped down anyhow, between tide marks or in shallow water. It will sometimes be ripple-marked, may be cracked when dried by the sun, may even catch and retain the prints of falling raindrops, while animals walking, crawling, or burrowing on or in it may leave tracks and traces. Sometimes such things are preserved if the oncoming deposit is suitable and laid down gently. Similarly, the coarser of the bedded rocks are irregular, like the sediments, and they are sometimes ripple-marked, sun-cracked, and even rain-pitted, while they are often marked with the trails or tracks of animals. In all this range of characters there is so close a resemblance between the group of bedded rocks and the sediments now forming that such rocks may be called "sedimentary," most of them also deserving the name of "aqueous" or water-formed.

Finally, if the sea-bed sinks and the water deepens, the successive belts of sediment will move inshore. Organic material may come to rest on mud, mud on sand, sand on pebbles. If the sea shallows, the belts will move out seawards, pebbles will rest on sand, sand on mud, and mud on organic material. Thus thicker layers or sheets of different kinds will come to alternate with one another. Exactly the same is seen in the sedimentary rocks—"strata" or beds of limestone resting on shales, shales on sandstones, and so on. The bedding must indicate such physical changes as the rise or fall of the sea-bed, and the consequent advance or retreat of the shore. Coarse on fine indicates shallowing, fine on coarse deepening, of the sea. Thus the reading and interpretation of the strata tell something of larger changes in the physical geography of the region where the sediments grew.

It is obvious that the order in which sediment now lies is that in which it was formed, the lower members of a series being the older and the upper ones the newer. So the order and sequence of the physical changes registered in the strata can be made out; and that is the physical history of the region in which the sediments were formed.

As the sedimentary rocks are now found far inland and often high up in the plateaux and mountains, it is evident that they must have been lifted by such movements as were indicated in an earlier chapter. In the process they become hardened, their layers are tilted and crumpled, and sometimes new structures are developed in the hardening sediments, giving them the characters displayed by them now in cliffs and quarries.

Just as the air and the water of the globe are in constant circulation, so the material of the solid land is undergoing a continual cycle of destruction, transport, deposit, and renewal, as the denudation and deposition coincide with the periodic uplift and depression of the solid crust. And the physical history of the land can be ultimately read in its cycles of uplift and depression, the former being accompanied by rock lifting and folding, by denudation and destruction, the latter by deposit, preservation, and renewal.

The following may be taken as an instance of the reading of the rock story as it is written in the laminæ of sediments. At a place called Oeninghen, in Switzerland, there occurs a little band of sedimentary rock, 2 inches thick, in which 250 laminæ have been counted. The few feet of rock of which this little band forms part have yielded 900 species of fossil insects, and they are hence called the insect beds. But they contain something else. Some layers are rich in the flowers of the cinnamon, due to flower in spring; other layers show fruits of willow and poplar which fall in summer, and still others the fruits of cinnamon and other plants which ripen in autumn. So the insect beds contain a calendar of the seasons of countless years ago.

It is but rarely that the geologist can reckon in seasons or years. He must usually be content with longer and less definite periods or epochs, such as are given by the thicker and more massive strata, examples of which are given in the Chalk, the Lias Clay, the Coal-bearing Rocks, or the New Red Sandstone.

The majority of the sedimentary rocks of Great Britain become coarser and thicker towards the west and north-west, as though land lay in that direction, while the examination of certain crucial deposits shows that the material of which they are composed could only have been derived from a westerly continental area. The mountains of Scandinavia and of north-eastern Scotland and Ireland are made of the right kind of stuff to yield such material, and their structures indicate that they are parts of what was once a continuous range that formed the framework of a North Atlantic Continent of sufficient magnitude to provide the vast quantity of detritus required for the rocks built during the long series of ages of Britain's geological history.

A continent, a veritable Atlantis, must have come into existence during the first half of the earth's history, so far as it can be read from the rocks, known as the Archæan Era. We know little or nothing of the life or physical history of this time, but in the next phase (the Older Palæozoic Era) a great submergence set in, extending up to and perhaps beyond the North-west Highlands, though the Atlantic continent on the whole maintained its position. This may be called Britain's first great marine period. Then broke out a chain of volcanoes,

[Photo : J. R. Stewart, reproduced by permission of British Association Geological Photograph Committee.

FIG. 6.—A FOSSIL FOREST OF THE CARBONIFEROUS AGE, PRESERVED IN WHITEINCH PARK, GLASGOW.

bordering the continent, or in festoon islands near its margin. They after a while quieted down, and a time of wide mediterranean seas followed, soon to be broken by a period of intense earth-movement and the growth of mountain chains, of which the Grampians and Southern Uplands of Scotland are instances, as well as the mountains of North Wales and Lakeland. In the hollows among these mountains was laid down the Old Red Sandstone made famous by Hugh Miller.

A second marine period succeeded, with extensive submergence of England and Ireland, and the making of the limestones that begin the coal-bearing rocks to which so much of the past prosperity of this country was due. These seas were slowly filled up with detritus worn off the Atlantis, and eventually their beds were overspread by deltas on which grew the forests that have turned into our coal-seams (Fig. 6).

Once again uplift and mountain movement followed. A large part of the former seas and delta became land. Chains like the Pennine, the Mendips, and the hills of South Wales and Devonshire originated. The land among them was converted into great salt lakes, that filled up with salt and gypsum coming from the evaporation of the briny water, with debris washed into them off the new-born mountains, or drifted in by the winds and sand-storms of the time (see Fig. 10). For the southern mountains had cut off the rain-bearing winds and made the climate dry and hot, and deserts spread over the land among the lakes or their dried-up beds, which bear to this day the tracks of the thirsty animals which came greedily to drink the last drops of water left.

Once again came the sea of mediterranean type, with a warm climate and hosts of shells, fishes, and even corals building their reefs; but gradually it deepened, till one of our most wonderful deposits, the Chalk, was formed, made very largely of such creature relics as now make the ooze of the Atlantic floor.

At last the great Atlantis disappeared, breaking up with a shock that gave rise to the greatest volcanic episode that Britain has ever been through, and one that extended from pole to pole. This, however, was but the overture to the vast earth-movement which a little later circled the Pacific with mountains, festoon islands, volcanoes, and earthquakes; while in the Old World it lifted the great range extending from the Pyrenees and Alps, through the Himalaya, to Kamchatka and Alaska.

Lastly crept on the Great Ice Age, when gradually the two hemispheres became enshrouded in ice, which flowed from Scandinavia to the latitude of the Severn and Thames, or that of Berlin, in the Old World, and from the Laurentian Highlands to beyond the Great Lakes in the New. From this we are now slowly recovering, both in the leisurely improvement in climate and in the equally deliberate uprise of the loaded land. We are living through the later stages of our last continental phase.

CHAPTER VII

The Evidence of Fossils

By SIR ARTHUR SMITH WOODWARD

WE have learned that most of the stratified rocks contain at least a few remains of the plants and animals which lived at the successive periods when the sediments were laid down. Hence it is possible to learn something of the way in which life has developed and spread over the earth.

These remains of former living things are generally known as " fossils," from the Latin word *fossus*, meaning dug—in this case, something dug up. They are also sometimes, especially in European continental languages, described as " petrefactions," meaning things turned into stone; but we do not use the word in this country, partly because not all fossils are mineralized, and especially because in English we wrongly use the word " petrefactions " for the objects that are encrusted with lime when they are placed under dripping wells which contain lime in solution.

Unfortunately, only very few of the remains of plants and animals buried in the sediments which become rocks are actually preserved as fossils. The water which saturates the rocks or oozes through them removes most of them, and this water often contains so much acid in solution that it can destroy even the skeletons themselves when they are of shell or flinty material. We know that this actually happens, from many familiar examples. In the quarries at Portland there is a layer of building-stone which was once a mass of shells and became hard while they were still there: they have now been all dissolved out by percolating water, and we see only the hollows which they occupied.

The water percolating or trickling through rocks always contains something in solution, varying from time to time according to the nature of the ground through which it has passed. It often contains mineral matter, which it deposits as soon as it reaches cavities, and when these cavities are, like those in the Portland stone, due to the removal of shells or other remains of plants or animals, the newly-deposited mineral reproduces the original shape. Many fossils, therefore, are merely casts or impressions of the remains actually buried.

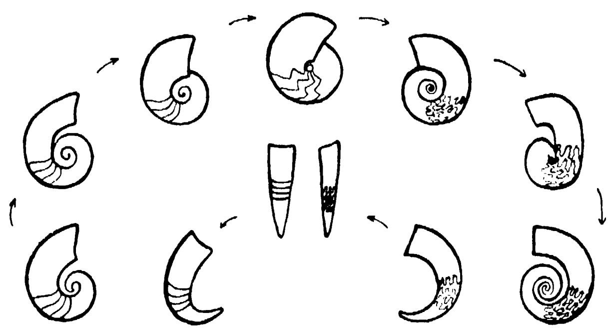
In most cases, however, the buried remains are not completely washed out to leave a corresponding cavity behind. The percolating water containing mineral matter fills every microscopic cavity of the buried shell or skeleton itself, and replaces the original substance, particle by particle, so that even its microscopical structure is preserved. This is the common condition of fossils, and the microscopic structures preserved by this kind of fossilization are astonishing. The effects even of bacteria, which cannot, of course, be preserved as fossils, may sometimes be seen in microscope sections of specimens from some of the oldest rocks.

Very often the amount of mineral matter in the percolating water is much greater than is needed to mineralize the fossils, and it accumulates in hard lumps round them, forming variously-shaped nodules, or "concretions" as they are termed. Thus were produced the flints in chalk, which were for the most part deposited around the remains of flinty sponges, and owe their shape to that of the masses of sponge contained in them. Thus also were formed the nodules of ironstone which are so common in the rocks associated with coal. When these nodules are split open, they often reveal the piece of plant, shell, insect, or fish which caused them to accumulate. It is especially important to understand the real origin of concretions, because many of them, especially the flints, mimic familiar objects—legs, arms, heads, and faces—and are often mistaken for fossils. The soft parts of bodies can never be preserved in such material, and any superficial resemblances to them are entirely deceptive.

The soft parts of animals are preserved only in the most exceptional local circumstances, and as a rule the only indications of them are impressions. The most striking cases of actual preservation are those due to freezing and natural antiseptics. Whole carcases of the extinct hairy elephant (the Mammoth) and Woolly Rhinoceros have been found both frozen in the Arctic regions and pickled by petroleum in a marsh at the foot of the Carpathian Mountains. The hair, skin, and other soft parts of Ground-Sloths were also found in the dust of a very dry cave in Patagonia, where their preservation seems to have been helped by the occurrence of saltpetre.

Until the various ways in which traces of plants and animals could be preserved in rocks were understood, a little more than a century ago, fossils were regarded only as curiosities, or at most treated as proof that there had once been a universal deluge. Some enlightened observers noticed that they seemed to indicate changes of climate, for remains of apparently tropical plants and animals had been found in the rocks of temperate regions; but, with the scanty knowledge of natural history at the time, it was impossible to reason further. It was only when it was discovered that rocks of different geological ages contained different fossils, and that rocks of the same age always contained approximately the same fossils, wherever they occur, that it became possible to use fossils for science. Then was founded a new branch of learning, Palæontology, which is compounded of three Greek words, meaning "the science of ancient beings." The Palæontologist henceforth began to study the life of the globe of long ages ago so far as possible in the same way as the ordinary botanist or zoologist studies the living things of the present day.

The first result of this study was the proof that the groups of plants and animals with which we are familiar had not been created all at the same time, but had gradually come into existence, some at one period, some at another, and that many had lived, flourished, and died out long before man appeared. It was also noticed that the order of their coming corresponded closely with the rank which they occupied in the scale of being, the lowest first, the highest last. The earliest living things, which probably swam and floated in the open sea, must have been soft-bodied, and so could not be preserved as fossils. The oldest fossils we know are the skeletons of animals which lived in the shallow water on the shores, and although they were already very varied, none of them had a backbone. It was not until long afterwards that animals with the beginning of a backbone made their appearance. They were very simple kinds of fishes. Then a few animals began to spread on the land, and insects were probably the first of these adventurers. Soon some of the paddle-finned fishes seem to have passed into salamander-like animals, which lived in the marshes and breathed air by lungs as soon as they were full grown. Next, there arose backboned animals which never used gills, but breathed by lungs as soon as they were hatched or born: they were thus able to spread over the dry land away from the swampy fringe. The world was now, indeed, becoming well occupied, for the backboned animals were accompanied by numerous air-breathers which had no backbone. The backboned wanderers still had blood no warmer than the surrounding air, and so corresponded in rank with the existing reptiles. They could live only in rather warm or hot regions. While these were still flourishing, a few backboned animals with warm blood began to appear, the forerunners of our birds and mammals or ordinary quadrupeds. Until this time the brain had been of little or no account, but the improved



[*From "Enchainements du Monde Animal," by Prof. Albert Gaudry.*

FIG. 7.

Diagram of the Shells of successive Members of a Race of Ammonites as they evolved during Geological Time, beginning with the left-hand straight shell and ending with the right-hand straight shell.

blood circulation was accompanied at once by an enlargement and complication of the brain. All the more important reptiles then disappeared, leaving only a few groups to occupy a comparatively insignificant place, chiefly in the tropics. The modern warm-blooded quadrupeds and birds took their place. As these quadrupeds spread into their several spheres of life their brains continued to enlarge and improve. Brain, indeed, had become the chief factor in success. Then in the end followed the climax of the whole procession of life : man with a strange overgrowth of brain which enabled him to dominate the whole.

Not only does the Palæontologist recognize this general progress in the world of life—he sees it also in every group which is sufficiently well known. For example, there once lived in the sea fish-shaped reptiles, the Ichthyosaurs or "fish-lizards." Like fishes, they swam by their tail-fin and only used their paired limbs for balancing. When they first appeared they had a very unsatisfactory tail-fin, which was not much more than a lash; next, there were fish-lizards with an excellent fan-shaped flipper, only handicapped by the thickness of the end of the backbone which was turned down into the lower lobe; finally, even this stiffening was reduced, and the latest fish-lizards flourished with the most efficient tail-fin imaginable.

The fish-lizards died out while they were still admirably adapted to the circumstances of their existence. Fossils show, however, that many groups of animals, after they reach their prime, do not die out and make way for others, but sink into a kind of old age, and end in a condition which may well be compared with what we call "second childhood." For example, the group of Ammonites, with chambered shells, more or less related to our existing Nautilus, flourished in all seas during many geological periods. In each race the earliest shell is straight, with straight-edged plates between the chambers (see Fig. 7). Next, the shell begins to curve a little, and the curvature soon becomes a spiral. The successors of these Ammonites have the coils of the spiral touching; and eventually there are some members of the race in which the coils are so much pressed together and altered in relative size that the outer coil completely envelops the others. By this time the edges of the plates dividing the chambers have become crinkled. The race has now reached its prime, and its next members have a shell which is beginning to show the inner coils once more. Then the shells of the successive geological periods uncoil more and more, until those of the latest members of the race, just before it dies out, are as straight as they were at the beginning: they are distinguished only by the crinkled edge of the plates. It is therefore allowable to conclude that there is some analogy between the life of a race of animals in geological time and the life of an individual in its brief span.

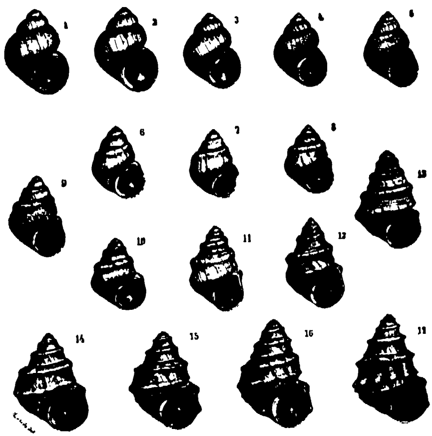
Chapter VIII

Animals of the Prehistoric World

By Sir Arthur Smith Woodward

THE facts dealt with in Chapter VII suggest that life on the earth did not appear in a series of separate creations, but that living things of one period gradually changed into those of the next period, and so on through all time. Even in the smallest particulars we can sometimes actually observe this gradual change. For instance, in the several layers of marl which have filled up an old lake in eastern Europe there are numerous shells of a pond-snail, named *Paludina* or *Vivipara*, shown in Fig. 8. All the earliest of these shells, which are of course in the bottom layer, are smooth, with beautifully rounded whorls. In the next layer most of the shells begin to show traces of a ridged ornament. In the still higher and thus later layers the ornament on many of the shells becomes more conspicuous; until in the latest layer of all most of the shells are very strongly ridged and often irregularly over-weighted with the thickening. Nearly similar gradual changes occur in the fossil sea-urchins named *Micraster* as they are traced through the successive sea-beds which form the white Chalk of England. The earliest forms, which are all similar in shape, have the shell nearly smooth. Their successors in the later layers change very gradually but uniformly in shape, and become more and more strongly tuberculated and encrusted with lime, until the latest forms have the thickest and roughest shells. We cannot study fossils, indeed, without arriving at the belief that the procession of life on the earth is due to the direct descent of one species from another, which also implies the direct descent of one group from another. For this phenomenon we use the technical term evolution.

If there has been evolution, we must of course expect to find among fossils the links between the successive groups of plants and animals, and be able to learn how, when, and where they descended from one another, or how they are related to one another. Unfortunately, however, the fossil record is too imperfect to teach us all we wish to know. The remains of living things are buried in rocks only by accident, and we have seen that even then they are often partially or completely destroyed during fossilization. We must also remember that we only find them by accident. In most parts of the world long periods of time are entirely unrepresented by fossils, and there are still large areas that have not been properly examined. There are also great tracts of former land now under the sea,



[*From "Erdgeschichte," by Professor M. Neumayr.*

FIG. 8.—A SERIES OF POND-SNAILS (PALUDINA OR VIVIPARA).

Found in successive layers of an old lake bed in Austria, showing how they gradually became ornamented and ridged towards the end of the Race.

and thus completely inaccessible for fossil-collecting. We must not forget, too, that groups of living things are always moving about from one place to another as circumstances change, so that we can rarely follow supposed pedigrees far in any one spot. Finally, we nearly always discover the best and most satisfactory fossils in great masses where the living things have been suddenly killed and quickly buried in some way; and these beds of fossils occur only at intervals, giving isolated glimpses of the progression of life. It is not surprising, therefore, that often we can trace the evolution of life only vaguely. The wonder is that in so short a time we have already found so much evidence of it.

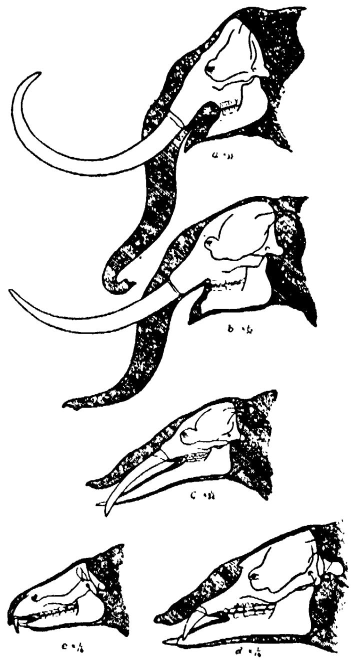
As sea-animals are more frequently fossilized than land-animals, because most rocks are the sediments of old sea-beds, we might expect to find the best evidence for evolution among them. So indeed we do, but as most of these animals are less familiar than those which live on land, I will only refer briefly to the fishes. Everyone knows that at the present day the large majority of the fishes (such as the herrings) have a backbone and other internal bones, a powerful tail-fin for swimming, and nearly always a light covering of thin flexible scales. They depend for their success in the struggle for life on rapid and dexterous movements. When the remote ancestors of these fishes first arose ages ago at an early geological period, the conditions of their life were totally different. As a general rule, then, animals competed in the struggle for existence by the possession of armour, and the thicker and stronger the armour the greater the chance of success. Swift movements apparently scarcely mattered. The earliest fishes were in the fashion of the time—nearly all their hard parts were outside. Instead of a backbone they had merely a flexible rod, and their internal skeleton was only of gristle; their tail was a kind of paddle adapted for leisurely movements rather than for rapid swimming; and their hard bony scales and armour-plates were reinforced by a covering of enamel. As we trace their successors (presumably their descendants) upwards through the rocks, we first find their fins changing—the tail-fin gradually becoming a more efficient propeller, and the other fins passing into perfect balancing organs like those of typically modern fishes. Next we find the flexible rod being replaced in slow stages by a typical backbone; and while the gristle of the internal skeleton is slowly hardening into bone, the outside scales and armour are gradually becoming thinner, until they are reduced to the typically modern flexible scales. The whole progress can be traced among fossils step by step, and one palæontologist has fancifully compared it with the development of the modern warship, beginning with a rivalry of armour which led to intolerable weight, and ending in an improvement of internal machinery which altered the rivalry to one of rapid and dexterous movement.

The most familiar instance of the evolution of a group of land animals is the oft-quoted genealogy of the horses. When it was first recognized by collecting fossils in a succession of old lake-beds and land-deposits in the west of North America, it could be traced in a vague way only; but during recent years the Americans have continued the collecting with such increasing care, obtaining better specimens and taking out the fossils layer by layer, that some of the evolution, at least, can now be traced in the greatest detail. There can be no doubt, indeed, that the horses came into existence in North America, and thence spread to the Old World. It appears that they began their career as dwellers in marshes, probably at a period in the earth's history before there were any plains covered with grass. These animals were no larger than foxes, and much like them in general shape, though with a much smaller brain. They were specially adapted by their low crushing teeth to feed on the juicy swamp vegetation; their neck was comparatively short; and their feet had spreading toes, so that they could walk on soft mud. But their feet were peculiar because the middle toe was a little stronger and larger than the others; in fact, one side toe in the fore-foot and the two outer side toes in the hind-foot were already lost except for a little piece of bone at the upper end. Their ancestors must have been five-toed, but they were beginning to have a foot which by very little change could be adapted for comfortable running on hard ground. For long generations the next horse-like animals continued to have low crushing teeth, but with a ridging of the surface which would enable them to live on hard leaves as well as juicy herbage; these animals grew larger, their neck was a little longer, and their middle toe became larger and stouter, with only a pair of slender toes hanging down at the sides. They probably lived among scrub and in forests. Later on in geological time came still larger animals in which only the baby teeth (or milk teeth) were low-crowned for crushing, while the permanent teeth which replaced them were deep grinders suitable for feeding on hard vegetation during a moderately long life. They had a longer and more flexible neck, and a longer face, which enabled them to browse on the ground even though their legs were becoming longer. Later there followed animals with a larger brain and still more flexible neck, which were essentially small horses, with powerful grinding teeth throughout life, and handicapped in running only by the pair of small toes which still hung down on the sides of each foot. They probably lived on the grassy plains which had now become a widespread feature of the earth. Then, finally, just before the appearance of man, came the finished horse, with its remarkable brain, its powerful grinding teeth fitted for a comparatively long life, its neck flexible for alertness, and its shape and one-toed limbs almost completely adapted for swift running over a hard surface. I say "almost" because the one-toed foot of the horse still retains as bony splints under the skin some remnants of the side toes, which often cause disease when the animals run on the hard pavements of our streets.

When we turn to familiar animals which probably evolved in the Old World, we meet with two special difficulties. The ancestors of these animals seem to have wandered about more than those on the American continent of which I have spoken; and their remains have not hitherto been found in a series of extensive superposed rocks like those of the Far West in the New World. Still, by bringing together scattered discoveries, we can learn a good deal about certain groups, and the broad outlines of the genealogies of the deer and elephants are especially interesting.

Long after the deer had come into being they were all without horns. It was only in comparatively late geological times that they began to grow these horns or antlers. At first the horns were very small throughout life, and never with more than one prong. Then, there were deer with two-pronged horns; later some of them had three- or four-pronged horns of considerable size; finally, just about the time when man appeared, some of the largest and strongest deer, like the so-called Irish Elk, grew complex horns sometimes eleven feet across, which must have been a hindrance rather than a help in the circumstances of their life. The race of deer, therefore, came to maturity by a series of stages, which are paralleled in the life-history of an individual modern stag. When it is born, the stag is hornless; at the end of the first year the horns are simple prongs; these are shed, and at the end of the second year the horns are forked; next year they bear two prongs, next three prongs, and so on, until the greatest complexity of the horns is reached at maturity. This parallel between the evolution of the race and the individual life-history of one of its latest members is often met with.

We will conclude with a reference to the genealogy of the elephants, which is perhaps the strangest of all that we are now beginning to understand. It is illustrated by Fig. 9. The earliest members of the race that we have hitherto recognized are found in river deposits in Egypt. They are small, plump, pig-shaped animals which must have lived on juicy herbage in marshes. Their head is long, and among their front teeth there is one pair much larger than the others, as if tusks were just beginning. The next animal that evidently belongs to the same race is found in a somewhat later river-deposit, also in Egypt. This is about twice as large as its predecessor, with much longer legs, but the neck not lengthened in proportion; consequently the front of the head is lengthened to enable it to reach the ground for browsing. The tusks are now the only front teeth left. The next later fossil elephants are found in Europe, and, with the same short neck, they have still longer legs, so that to reach the ground the face and lower jaw are even further lengthened. In all these animals, striving to browse on the ground, the bone only of the lower jaw is lengthened; that of the upper jaw remains comparatively short, so that the whole of the very long face is made of flesh and other soft parts. Eventually this arrangement becomes mechanically impossible, and in the later fossil elephants the bony chin shrivels up, leaving the long soft face to hang down and devise a new way of feeding. In the latest and modern elephants the lower jaw is even shorter than the skull, so that the hanging soft face becomes a completely effective proboscis. The elephants have thus been preserved from extinction only by a peculiar makeshift which is not seen elsewhere in the animal kingdom, and a palæontologist naturally wonders what kind of a restoration of an elephant he would have made if he had only known it from its skeleton.



[*Professor R. S. Lull.*

FIG. 9.

Diagrams of the Skull and Proboscis (or Trunk) of the successive Ancestors of the Elephant, showing how, beginning with a pig-shaped skull (*e*), the shortening of the bony face (*d*) and the lengthening of the lower jaw (*c*) produced a long fleshy snout, which, when the lower jaw also shortened (*b*), left the fleshy snout hanging down as a proboscis.

CHAPTER IX

What Coal Reveals

By Professor A. C. SEWARD

IN old days it was believed that the various kinds of animals and plants were separately created; each sprang into existence as a new creation. Professor Huxley is reported to have said that, if you do not believe in evolution, you must not be surprised when you come down to breakfast in the morning if you see a brand new sort of animal sitting on the lawn. It was, of course, realized that, once established, a plant or animal reproduces its kind; like produces like. The idea of the production of an animal or plant, very unlike its far-off ancestors, by gradual changes from generation to generation, was not entertained. Charles Darwin published his greatest work, the *Origin of Species*, seventy-one years ago. Before 1859 a few naturalists had expressed the opinion that the several kinds of plants and animals have been produced, or evolved, as the result of the gradual alteration of older forms. But the development of one form of animal or plant from another was not accepted by the great majority of men of science. Darwin was the first to give a clear account of what is called evolution: he thought of living things not only as we know them to-day, but as the descendants of ancestors which, if they could be traced back through the ages, would be found to become more and more unlike the modern representatives of the race. He believed that when the earth was young there existed a comparatively small number of simple animals and plants, and that in the course of the hundreds of millions of years of the earth's history endless forms, "more beautiful and more wonderful"—as he wrote in that splendid final paragraph of the *Origin of Species*—"have been and are being evolved." The last chapter, especially the latter part, should be read by all who wish to know what Darwin's position was.

The vast majority of educated people are now convinced that there has been an evolution, a gradual unfolding of life from the simple to the less simple; a progress from very small living things, visible only under the microscope, to larger and more complex, from which, in turn, were produced still larger and more elaborately constructed descendants. We know that even so complex an animal as a human being begins as a minute speck of living material which becomes gradually larger and more wonderful in structure until the child is born. This occupies less than a year; if we think of generations of animals or plants slowly changing into more and more wonderful forms in the course of millions of years, the idea of evolution is easier to grasp. Instead of the gradual change in a single individual completed in nine months, let us think of a long succession of individuals and families changing very slowly from age to age in the course of millions of years. In this way we can see more clearly what is meant by evolution.

Darwin spent the greater part of his life collecting facts and asking questions of nature, and at last gave his opinion on the way in which the unfolding of life has been accomplished. There is still much difference of opinion among students on the methods of evolution. We are still groping for answers to the great question,—how plants and animals, as we know them, have been produced from older forms of other days.

Let us now confine ourselves to plants. Everyone knows that plants are of many different kinds. Trees with small inconspicuous flowers, such as the oak; shrubs, and the smaller herbaceous plants are all members of one great group—the flowering plants. Trees such as pines and firs do not produce what we usually call flowers; they bear cones and are grouped together as conifers. Ferns, club mosses, and horsetails, members of the fern group, produce neither flowers nor seeds, and reproduce their kind by very tiny bodies known as spores. Still humbler and simpler plants are the mosses and the seaweeds and related plants which live in fresh water and on land; some are too small to be seen with the naked eye, and are among the simplest of all known plants. Finally, there are the fungi, that is, mushrooms and toadstools and many other sorts, which live as parasites on animals and plants or in decaying matter in the ground; also the excessively minute bacteria.

What do we know of the past history of this plant-world? If we study the plants around us we see no signs of any change from one sort to another; each repeats its kind, and the whole vegetable kingdom seems to be fixed and unalterable. Plants wander from place to place, seeds are driven by the wind, carried by birds, or transported by water; but we are not conscious of the evolution of new kinds. On the other hand, the fact that plants have been divided into groups and families means that botanists believe that members of each group have come from some common ancestor. In order to trace the history of the plant-world we have to go to the rocks and look for the remains of leaves, stems, and seeds which are preserved as fossils.

We will now transport ourselves to an age separated from the present by hundreds of millions of years, to a world which would look unfamiliar could we see it on a map. Many thousands of square miles in Europe, Asia, and North America were covered with forests. We may speak of this stage as the Coal Age, because from its rocks most of our coal is obtained. A piece of coal does not look very promising as a guide to the kinds of plants which grew in the old forests; but sometimes a block of coal taken from the coal-scuttle has regular markings which represent the impression of a piece of stem or branch. Thin sections of coal examined under the microscope often show small and bright orange-coloured patches, which are spores, and other fragments of plants of the Coal Age forests. It is not only in the coal itself that remains of plants are found: the largest specimens occur as impressions on the surface of a rock known as shale, which was once soft mud, and is taken from collieries as refuse.

The coal itself is to a large extent made of the altered remains of plants: it is a compact mass of fragments pressed together and gradually altered into coal. It is often compared with peat, which anyone can see is made of plants; peat is much younger than coal, and the vegetable material has not undergone so great a change. In places where coal is worked there are beds of shale with the coal. What does this tell us? The coal marks the site of a forest: it is all that is left, after an enormous lapse of time, of forests which once flourished at or very near to the place where the coal is now found. The shale above a bed of coal tells us that the forest was eventually submerged; the water which drowned the trees carried with it mud, which gradually collected in layers and became hard shale. The fossil plants we see on pieces of shale are the leaves, twigs, and other waifs and strays which fell into the water as it spread over the forests. It has been possible to find out a great deal about the plants of the Coal Age. We know not only the external form and pattern of the leaves and stems; but thin sections of hard balls found in some beds of coal show under the microscope the most delicate structure of plants which lived millions of years ago.

Let me now try to picture a scene in a forest of the Coal Age: swamps stretching as far as the eye can see; trees growing to a height of 100 feet or more, many of them with the lower parts of the trunks in water, others rooted in dry ground. Some of the more conspicuous trees have gradually tapering stems, from which at intervals are given off circles of spreading branches bearing still smaller circles of narrow leaves in star-like clusters. These plants are known as *Calamites*, and may be compared with our familiar horsetails, which grow in England as common weeds; but the calamites were much taller, and had hard, woody stems; our modern horse-tails are never hard and woody, and in this country are rarely more than five feet high. The resemblance between calamites and horsetails is close enough to show a relationship; the horsetails may not be the direct descendants of the calamites, but among living plants they are by far the nearest to those ancient trees of the Coal Age. It is reasonable to suppose that both trace back their history to the same group of ancestors. Another tree, often taller than a calamite, has long trunks like columns which, as they soar upwards, fork into branches, and they in turn divide into still more slender arms, covered with short needle-like leaves and bearing long and narrow cones full of spores. These trees, known as *Lepidodendron*, are related to our club mosses (*Lycopodium*) and similar plants, and are included by botanists in the great group of ferns and fern-like plants. In them, as in the calamites, we notice that the chief difference between the present-day plants and their relatives of the Coal Age is that the older forms were large and woody trees, while the living members of the same group are much smaller and simpler. A common tropical club moss is like a miniature tree, and therefore more comparable with the tall trees in the forests of the Coal Age than the British club mosses.

It used to be thought that ferns were among the commonest plants in the forests of the Coal Age. We now know that many of the supposed fossil ferns, though similar in appearance to ferns, produced seeds, and not spores. They are among the most interesting of all fossil plants. No living fern produces seeds; ferns are lower in the scale of plant-life than plants which have seeds. The plants of this group, although the commonest plants in the Coal Age forests, have no survivors in the world to-day. There were some real ferns as well, though they were comparatively rare; but, so far as we know, flowering plants were completely absent from the Coal Age forests. At the present day the flowering plants play the chief part in the plant-world; in the Coal Age the seed-producing, fern-like plants were the most abundant. There were no pines and none of the present-day conifers, though there were trees related to them.

A wanderer from the world, as it is to-day, in a forest of the Coal Age would soon realize that he was in a strange land; a world without flowers, with no birds nor many other animals such as we expect to see in forests. He would see trees reminding him at a distance of familiar pines and conifers; but on closer inspection he would think of them as gigantic relatives of horsetails and club mosses. He would see what appeared to be a wealth of ferns, tall tree ferns and many smaller kinds; again on closer view he would find that on many of the supposed fern fronds were seeds, some as large as hazel nuts.

The fossils show that during long ages groups of plants made rapid progress, and then gradually, or sometimes suddenly, declined in vigour, and finally ceased to exist. The path of plant evolution is strewn with what seem to be failures or unsuccessful experiments. By following the march of plant-life through the ages, we learn that evolution has not been a straightforward advance from low to high, from simple to less simple; plants that are small and inconspicuous to-day are often members of a race which in former times was a race of giants. The more we learn of the vegetation of the past the more difficult becomes the search after origins and the beginning of things. We soon discover that the problems presented to us, as we attempt to follow the course of evolution, are still far from being solved. Some day it will be possible more accurately to reconstruct the past and to follow the chains of life from one age to another. We are still far from solving the riddle of Creation.

CHAPTER X

Changes of Climate in the World's History

By Professor A. C. SEWARD

IS there good reason to suppose that the climate of the world was in former times different from what it is now? How do we set about trying to find out what sort of climates there were at different periods of the world's history? In order to obtain facts likely to throw light on what has happened in the course of hundreds of millions of years before man came into the world, and therefore long before there was any written history, we have to search among the rocks which form the surface of the earth and can be examined in quarries, in cliffs and ravines, in mines and other places. Rocks are of many different kinds and of many different ages; they are the documents from which it is possible to follow in some measure the successive events which make up the history of the earth. Geologists have classified the rocks into several groups of systems, each of which represents, as it were, a chapter of earth-history: these chapters are known as geological periods.

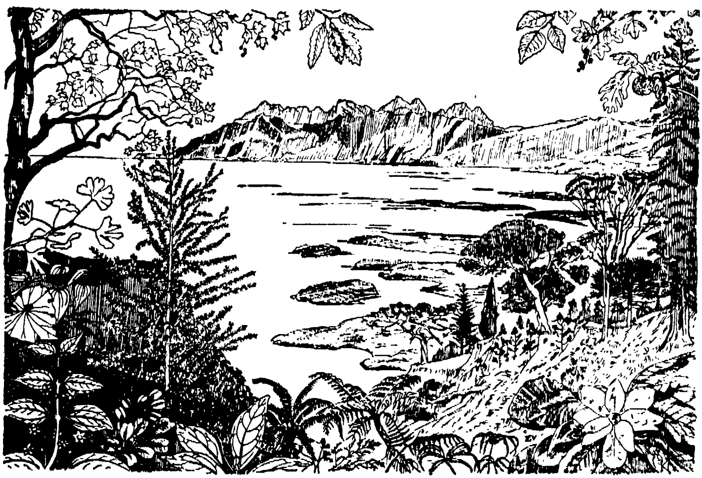
Near the centre of England, in the Charnwood Forest district of Leicestershire, there are low hills made of hard rocks like granite. Some of the granitic hills were once covered by softer material that was spread out in layers of sediment from muddy water. In course of time these newer layers of rock were removed by air and water, rain and frost; and parts of the buried granite were gradually exposed to view. In the hills thus exposed we have a glimpse of a very old landscape, a piece of the earth's surface as it was before the mud and sand levelled the uneven floor of the older rocks. We can, therefore, form some idea of the state of the country which for long ages had been hidden. The exposed surface of the older rocks had been smoothed and polished and worn into broad grooves and rounded ridges: surface-features which remind us strongly of those seen on hard rocks in deserts of the present day, and produced by storm-driven blasts of sand. This comparison suggests that at one period there may have been a desert in the region that is now Leicestershire. The striking photograph of a piece of this old desert landscape (Fig. 10) was published by Professor Watts, who described this impressive link with the past. But are there any other facts in support of the existence of desert conditions? In Cheshire and Worcestershire there

[*P. W. Wright.*

FIG. 10.—LEICESTERSHIRE ROCKS WHICH WERE EXPOSED TO SAND STORM IN A TRIASSIC DESERT.

are beds of salt and gypsum, reminding us strongly of deposits now being formed in the Dead Sea and in other very salt waters in dry countries. The English salt beds belong to the same period of the earth's history as that in which the granites of Leicestershire were grooved and polished by blasts of desert sand. Some sandy rocks which belong to this geological period are made of small particles with the same shape as the well-rounded grains in present-day deserts. We know that during a certain stage in the past history of this country there were desert conditions where now there is a typical English scene.

Let us next look at the fossil plants which have been found in such rocks as sandstones and shales. It is common knowledge that in our climate it is impossible to grow out of doors many of the plants sent to us from warmer countries; they must be grown in hothouses. Can we then use fossil plants as thermometers to follow changes in temperature in the past? We can to some extent; but only partially. In the first place, the plants obtained from rocks belonging to the more ancient periods, such as the Coal Age, are very different from any now



[*Drawn by E. Vulliamy for a forthcoming book by A. C. Seward on "Plant Life Through the Ages."*

FIG. 11.—A RECONSTRUCTION OF CRETACEOUS GREENLAND.

living; and though we can learn from their structure something of the conditions in which they grew, we cannot say much, with great confidence, about the climate which they required; they are too unlike any living plants with which they can be compared. But collections of fossil plants from periods of the earth's history nearer to the present resemble more closely plants which are living now, and it is therefore safer to make comparisons with regard to climate.

Let me take as an illustration plants collected in Greenland: the rocks which furnished them belong approximately to the time when our Chalk was being formed on the ocean floor; this period is known as the Chalk, or Cretaceous Period, from the Latin word *creta*, which means chalk. Halfway along the west coast of Greenland, in Disko Island and in the cliffs and valleys of the neighbouring mainland, are sandstones and shales, which were no doubt formed at a time when what is now high ground in western Greenland was the estuary of a large river. The river gradually built up a delta of sand and mud and swept in leaves and branches of trees; so samples of the vegetation growing on the banks were buried as fossils in sand and mud. Many of the fossils are broken fern leaves. The commonest agree closely with different kinds of *Gleichenia*, which are members of a family now widely spread in tropical countries south of the equator. There are no gleichenias in Europe at the present day. This means that at one time—millions of years ago—there lived in Greenland ferns which were members of a family that in the course of ages wandered far to the south from Arctic regions, and eventually settled in Central and South America, Africa, the Malay Archipelago, and farther east, several thousand miles away from its original home in the far north. If most of the living members of this family of ferns are tropical, are we to conclude that, when very nearly related ferns lived in Greenland, that country enjoyed a tropical climate? It would be going too far to answer the question by a simple "Yes." We can only suppose that Greenland in the Cretaceous period was much warmer than it is now.

With the fossil ferns are leaves and twigs of many other kinds of plants. Some of the fossil twigs and cones are very like those of one of the big trees of California which is often grown in our parks; it is known as *Sequoia* and now grows wild only in California; it is certain that trees nearly related to it once flourished in Greenland. Many of the leaves can be closely matched with those of the living plane trees and of Magnolia. The majority of the trees which have left their foliage in the rocks of Greenland are now living either in the south of Europe, in the southern United States, or in tropical countries.

Let us next look at Greenland as it is. By far the greater part is deeply buried under perpetual ice, and is practically destitute of life. During the short summer a comparatively narrow strip around the coast has little or no snow, and flowers are abundant. In that part of Greenland where the fossils occur there are now no trees, only stunted willows that rarely reach a height of more than two or three feet, and the dwarf birch. The hill slopes are in places covered with a vegetation reminding us of our own moorland, but there are no trees, and the heather of the British Isles is replaced by another member of the family ; many small flowering plants grow on hills and in valleys which are free from snow in the summer, and some of them are well known on the Scottish mountains and in the English Lake district. In the Chalk period there was a rich vegetation made up of many different kinds of trees and shrubs instead of the low-growing Arctic plants of to-day : there were many ferns differing widely from the few which now grow in Greenland. In a word, the contrast between the forests which have left their scattered fragments in the rocks and the vegetation which now produces attractive flowers in the short summer is about as great as it could be.

There have been many great changes in climate in the course of the earth's history, and there is no good reason for believing that the world, as a whole, received much more heat from the sun millions of years ago than it does now. How, then, can we explain differences in climate between the past and the present? It is impossible to discuss this difficult question briefly : we know that places where there is now dry land were once under water, and regions now below the sea were at one time above it. Alterations in the position and size of continents change the flow and direction of ocean currents which, like the warm Gulf Stream and colder currents flowing from the polar seas, raise or lower the temperature of continents and islands. The gradual lifting up of mountain-ranges also makes a considerable difference in the climate ; and there have been many such uplifts in the course of geological history.

It is, however, hard to believe that changes in the position of land and sea and in the height of land above sea-level would make enough difference in climate to account for the contrast between the present and the past.

Chapter XI

Man in the Making

By Sir Arthur Smith Woodward

THERE are several reasons why students of fossils think that the human frame is the natural end of the procession of living things on the earth. First, we have seen that of all the important parts in the body of backboned animals, the brain was the latest in geological time to develop in complication and size; and man is unique in the overwhelming power of his brain, which suggests that he comes at the end of the series. Secondly, it is clear that the most complicated brain in any known animal occurs in the monkeys and apes; and they, of all animals, agree most closely with man in the structure and arrangement of every part of their body. Then we have reason to conclude from fossils that the monkeys and apes came into existence long before man; and we know that the human body differs most fundamentally from the ape body in the relatively large size of the brain, with its expansion especially in those regions which denote the higher faculties. We have learned from fossils that, when one particular structure in any group of animals gradually increases in size and complication in successive generations, it often tends to grow to excess; so that it would be quite in accordance with known principles or laws if some of the early ape-like animals began to show the overgrowth of brain which reached its extreme in man, who succeeded them in time. Again, we actually know several fossil ape-jaws, notably those named *Dryopithecus* from the Middle Tertiary rocks of Europe, which have a much more human bony chin and more nearly human grinding teeth than any existing ape. And finally, the few oldest fragments of fossil human skeletons which have hitherto been discovered exhibit more resemblances to the skeletons of apes than do those of any modern men. The top of a skull named *Pithecanthropus*, for example, found in Java, is mainly human, but has great bony brow-ridges like those of most apes. The lower jaw of the primitive human skull found at Piltdown, in Sussex, has upstanding canine (or corner) teeth which would work like those of apes; and both this and certain lower jaws from very ancient deposits in Germany and in China have a bony chin which is as much like that of an ape as that of a man. The whole skeleton of the still later fossil Mousterian or Neanderthal man of Europe also shows a series of ape-characters which never occur together in any modern human skeleton.

The difficulty is that so far we have found very few fossil fragments of the skeleton of the ancient apes and the earliest men. Both apes and men are especially wary creatures, capable of avoiding many accidents which would preserve their remains in rocks. A large proportion of the modern apes, when they reach feeble old age, are caught and eaten by leopards and other beasts of prey, and there can be no doubt that the apes of former geological periods were destroyed in the same manner. We can only state at present that all the scanty fossils we know favour the idea which we have formed on general principles, that both modern apes and men have evolved in different directions from the same ape-like ancestors. We know enough to feel sure that man originated somewhere in the Old World, where the man-like apes were formerly much more widely distributed than they are to-day. From the beginning he was a maker of tools, and therefore, if we can recognize his successive settlements, we are able to trace his progress towards civilization.

The earliest settlements seem to have been along the wooded banks of streams, where his shelters were probably nothing more than branches of trees covered with skins. For all the earliest bits of flint and other stones which appear to have been chipped by man to make them useful are found in old river deposits. He doubtless picked up any piece of wood or stone which would serve his purpose, and merely broke away an inconvenient projection or chipped an edge to sharpen it. The bits of wood have perished, but we often find the stones, which experts think must have been chipped by man. Some of them cannot be recognized with certainty; but many of the so-called *eoliths* and *rostrocarinates* seem to have been shaped with intelligence.

In other river deposits which geologists can definitely refer to a later geological period we find lumps of stone (chiefly flint in western Europe) which have certainly been chipped by man into a rough pear-shape. The heavy end would be held in the hand, and the pointed end, with its sharp edges, would be used for the various purposes of primitive life—cutting and scraping skins, flesh and bones, splitting wood, opening nuts, and so forth. These tools are remarkably uniform in shape, proving that when man began to fashion stones for himself he was satisfied with one general pattern for many purposes; but it is interesting to notice that, as his efforts are traced through deposits of successive ages, he shows marked advance in skill, the earliest tools being only roughly chipped, and often retaining a bit of the outside surface of the original lump from

Illus. London News.

FIG. 12.—FROM APE TO MAN.

which they were made, while the latest tools of the same pattern were most beautifully and finely chipped into shapes which vary more in thickness and in the rounding of the contour. The same race of men probably also used wood and bone, but the wood has perished, and the only piece of worked bone hitherto discovered is a large flake about sixteen inches long, split from the thigh-bone of an elephant and shaped almost like a cricket-bat, which was found with the Piltdown skull in a river-gravel in Sussex. The Piltdown skull and the lower jaws from Heidelberg, Germany, and Peking, China, probably belong to the men who made these tools, and show that they represented more than one race with a very ape-like jaw.

The men who made the nearly uniform lumpy and pear-shaped stone tools still lived mostly in temporary shelters on the wooded banks of rivers; and because the poorer and finer examples of their handiwork were first studied respectively in the river-gravels of Chelles and St. Acheul in France, we generally speak of them as representing the Chellean and Acheulean periods. Some tribes of these races of man, however, were beginning to live in the more permanent shelter of caves.

The first true cave men of western and southern Europe and Syria had learned to make much more varied stone tools, each specially adapted for its own purpose. The earlier men, as a rule, had merely taken a lump of stone and chipped it to the conventional shape. These pioneer cave men, on the other hand, split the stone first into flakes, and then trimmed those to the shapes required. They thus achieved a great advance in handicraft. Their tools were first studied in the cave of Le Moustier in the Dordogne, Central France, and hence their period is named the Mousterian. The first example of their skeleton was found in a cave in the Neanderthal, near Düsseldorf, Germany, and hence they are often described as the Neanderthal men. They are the oldest race of men who are known to have buried their dead, and the burials are of extreme interest, because they seem to show that the race of Mousterian or Neanderthal men had already formed some idea of a future life. One burial of this period, at least, in a small cave at La Chapelle-aux-Saints in Central France, was very carefully studied, and showed that the body had been provided not only with an ample supply of stone tools, but also with the leg of a bison, which must have been covered with flesh when it was buried and was doubtless intended for food for the deceased. This advance in mental outlook is all the more remarkable because Mousterian man shows a combination of ape-characters in his skeleton such as is never seen in later and modern man. At the same time, it must be remembered, he had a brain larger than that of the average European to-day.

The next cave men over a very large area of the Old World are shown by their carefully buried skeletons to have been in every respect like modern men. Such burials were first found in the small rock-shelter of Cro-Magnon in the Dordogne, and it is now known that the Cro-Magnon race was very widely spread among the peoples of its time. These cave men not only made a very varied assortment of tools from flakes of flint and sometimes other stone, but also used bone and ivory extensively, both for tools and for ornaments. They had, indeed, begun to appreciate art, or at any rate to suspect that artistic efforts had some important influence on supplying the wants of their everyday life. They made beautifully symmetrical bone harpoons, and they also made bone arrow-straighteners like those of the modern Eskimos, showing that they used either darts or arrows of wood. They had bone needles for sewing together skins with sinew thread; and they had well-shaped bone pins, and necklaces of perforated teeth. Many of the bone implements were ornamented with conventional lines or with incised drawings chiefly of animals of the chase, and some were even carved into the shapes of these animals. Excellent and spirited drawings of the same animals were also made on broken pieces of bone and antlers of deer. Carved ivory statuettes of women and ivory rings are also not at all uncommon. Still more remarkable, at least in France and Spain, these later cave men often penetrated from their living places at the cave mouth to the dark inner recesses of the cave, and even in the remotest and most inaccessible points they covered the walls with drawings and paintings, again chiefly of the animals which they hunted. There cannot be much doubt that man had now acquired some ideas of magic. These lifelike drawings, hidden from the outer world and treated with due ceremonial, would be regarded as helping him to success in the chase.