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The Presidential Address.

Form, Drift and Rhythm of the Continents.

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IT is now sixty-seven years since the British Association enjoyed the hospitality of the city of Norwich, a privilege which is being renewed to-day under the most happy auspices.

At that meeting we find the scientific community was particularly interested in underground temperatures and tidal phenomena, in the application of the spectroscope to celestial objects, and in the discovery of the oldest Cambrian fossils and the earliest fossil mammals then known. Many papers were read on local natural history, including those on Norfolk farming and the drainage of the County and of the Fens.

In his address at the meeting the President, Sir Joseph D. Hooker, made special reference to the work of Charles Darwin: not to the *Origin of Species* which had been acrimoniously discussed by the Association on previous occasions, and notably at Oxford in 1860, but to some of the work that followed.

It should be remembered that Hooker was one of the three scientific men, representing botany, zoology and geology, whom Darwin had selected as judges with whose opinion on the soundness of his theory of the origin of species he would be content. The others were Huxley and Lyell; and of the three Lyell was the hardest to convince, chiefly because the record of life in the past then furnished by the rocks was manifestly so incomplete and unsatisfactory that its evidence was insufficient to warrant a definite verdict.

Lyell had set out to 'treat of such features of the economy of existing nature, animate and inanimate, as are illustrative of geology,' and to make 'an investigation of the permanent effects of causes now in action which may serve as records to after ages of the present condition of the earth and its inhabitants.' By laborious study of the work of others, and by his own extensive travel and research, he had been able to enunciate, for the inorganic world, the principle of uniformitarianism, which in its original form we owe to Hutton. This principle involved that the history revealed by the rocks should be read as the effect of the slow but continuous operation of causes, most of them small, such as could be seen in action in some part or other of the world to-day. This was set in opposition to the opinion of the older geologists who had postulated a succession of catastrophes which, by flood, fire and convulsion, had periodically wrecked the world and destroyed its inhabitants: each catastrophe necessitating a new creation to provide the succession of life on the earth as it then was known.

But in the organic world Lyell, like Hutton, had failed to detect any analogous principle, and, as he rejected all the theories of transmutation of species then in vogue, he had to accept their absolute fixity; and to suppose that, as species became extinct one after another, replacement by special creations followed. And yet the reading to-day of the chapters devoted to this branch in the earlier editions of Lyell's great work produces the haunting feeling that a better explanation had only just eluded him. It was the story revealed in Lyell's work, Darwin tells us, the new conception that the earth had been in existence for vast æons of time, the proof that it has been continuously peopled by animals and plants, and that these had steadfastly advanced and improved throughout that time, which showed him the necessity for an explanation of the progression of life, and gave him the first hints of his theory. When he had enunciated this he was enabled to repay his master with the principle of organic evolution, which brought changes in the animate world into harmony with those of the inanimate.

His *Antiquity of Man* shows that by

1863 Lyell had become a convert, and he afterwards rewrote much of the second volume of his *Principles* accepting the new point of view. This change earned from Hooker a testimonial in the 1868 address which, if not unique, must certainly be one of the most magnificent ever awarded to a scientific work:

'I know no brighter example of heroism, of its kind, than this, of an author thus abandoning, late in life, a theory which he had regarded as one of the foundation stones of a work that had given him the highest position attainable amongst contemporary scientific writers. Well may he be proud of a superstructure, raised on the foundation of an insecure doctrine, when he finds that he can underpin it and substitute a new foundation: and, after all is finished, survey his edifice, not only more secure, but more harmonious in proportions than before.'

Although infinitely richer than when Darwin wrote, the Geological Record still is, and must from its very nature remain, imperfect. Every major group of animal life but the vertebrates is represented in the Cambrian fauna, and the scant relics that have been recovered from earlier rocks give very little idea of what had gone before, and no evidence whatever as to the beginnings of life.

But, from Cambrian time onward the chain of life is continuous and unbroken. Type after type has arisen, flourished and attained dominion. Some of them have met extinction in the heyday of their development; others have slowly dwindled away; others, again, have not finished their downhill journey, or are still advancing to their climax.

Study of the succession of rocks and the organisms contained in them, in every case in which evidence is sufficiently abundant and particularly among the vertebrates and in the later stages of geological history, has now revealed that the great majority of species show close affinities with those which preceded and with those which followed them; that, indeed, they have been derived from their predecessors and gave origin to their successors. We may now fairly claim that palæontology has lifted the theory of evolution of organisms from the limbo of hypothesis into a fact completely demonstrated by the integral chain of life which links the animals and plants of to-day with the earliest of their forerunners of the most remote past.

Further, the rocks themselves yield proof of the geographical changes undergone by the earth during its physical history; and indicate with perfect clearness that these changes have been so closely attendant on variation in life, and the incoming of new species, that it is impossible to deny a relation of cause and effect.

Indeed, when we realise the delicate adjustment of all life to the four elements of the ancients which environ it, air, water, earth and fire; to their composition, interrelationships and circulation; it is perhaps one of the most remarkable facts established by geology that, in spite of the physical changes which we know to have occurred, the chain of life has never snapped in all the hundreds of millions of years through which its history has been traced.

The physical changes with which Lyell and his successors were most closely concerned were, firstly, the formation of stratified rocks on horizontal sea-floors, situated in what is now often the interior of continents, far removed from the oceans of the present day, and thus indicating important and repeated changes in the position of land and water; and, secondly, the deformation of these flat deposits till they were rucked and ridged to build the mountain ranges.

Before and since Lyell's time geologists have devoted themselves to working out the exact and detailed succession of these stratified rocks, translating their sequence into history and their characters into terms of geography; the succession of physical conditions prevailing at the time of their formation. Further, although animals and plants migrate from place to place, the time occupied by the migrations of suitable forms is so negligible when compared with the length of the chapters of geological history that their fossil remains have proved to be the best means for correlating strata over broad stretches of the earth's surface. This correlation has converted the fragments of local history thus revealed into at least the outlines of the geological story of the world.

It was not till 1885, however, that the accumulation of data of this type was sufficient to enable the great geologist, Suess, an Austrian but born in this country, to assemble and correlate them, and to deduce from them further principles which have been the mainstay and inspiration of his successors. We owe to Hertha Sollas and her father the rendering of this great work, *The Face of the Earth*, into English; and to Emmanuel de Margerie and his colleagues a French translation enriched with a magnificent series of maps and sections such as could only have been brought together by one with the most remarkable bibliographic knowledge ; a veritable recension of the original.

The nature and associations and the distribution in time and space of modern changes in the relative levels of land and sea, as detected at sea-margins and by altitude survey, and of older changes betrayed by such evidence as submerged forests and raised beaches, had convinced geologists that the unstable element was not the fickle and mobile sea, but the solid if elastic earth-crust. They naturally applied the same explanation to those encroachments of the sea in the past which had resulted in the formation of our stratified rocks. But while some investigators were content with one form of movement—that due to lateral pressure—to explain both the formation of mountains and the rise and fall of the land, others called in a different cause for the latter. Without entering into a discussion of causes it may be well for us to distinguish the orogenic or mountain-forming from the epeirogenic or continental movement.

The evidence collected by Suess proved that these last great land and sea changes had occurred simultaneously over whole continents or even wider regions. Such great submergences as those to which the Cambrian Rocks, the Oxford Clay and the Chalk are due were of this character ; while, in between, there came times of broad expansions of continental land and regressions of the sea. These changes were in his view on far too grand a scale to be compared with, or explained by, the trivial upheavals and depressions of land margins of the present day, which he showed could mostly be correlated with volcanoes or earthquakes, or with such incidents as the imposition or relief of ice-sheets on an elastic crust in connexion with glacial conditions.

It became necessary for him to replace or supplement oscillations of the earth-crust by a world-wide periodic ebb and flow of the oceans, to and from the continents ; positive movements of transgression carrying the sea and its deposits over the lands, drowning them and their features under tens or hundreds of fathoms of water ; and negative movements or regressions when the oceans retreated to the deeps, leaving the continents bare or encrusted with recently formed sediments.

Although the facts cried out for this generalisation Suess was at a loss to supply any mechanism competent to produce the wonderful rhythm. The problem was difficult because a liquid must maintain a horizontal, *i.e.*, an equipotential, surface. It was manifestly impossible to withdraw from the earth, and later to replace upon it, the vast quantity of water that would be required ; and, though a shifted water-level, or even a varied water-surface relative to the continents, might be caused by polar ice-caps, by redistribution of the continents carrying their local effects on gravitation, by variations in the rate of the earth's rotation, or other far-reaching causes, none of these would supply an explanation that fitted all the facts. Regressions of the sea could be to some extent explained if Suess's main postulate, that the great ocean basins had been slowly sinking throughout geological time, were granted. But this explanation only rendered more impotent the raising of ocean levels by deposits of sediment, and this was almost the only valid cause for transgressions that he had been able to suggest.

Further, it is not possible to ignore the definite relationship that exists between the pulsation of the oceans and the raising of mountains by lateral or tangential stress. Periods of positive movement or advance of the seas were times of comparative tranquillity, when tangential pressure was in abeyance. Periods of negative movement and retreat were invariably marked by the operation of great stresses by which the earth's face was ridged and wrinkled in the throes of mountain-birth.

The theory that continuous cooling and shrinkage of the interior of the earth afforded an explanation of mountain ranges and other rugosities on its surface was a legacy from the nebular hypothesis. In spite of the homely simile of a shrivelling apple, this explanation has never received a very enthusiastic welcome from geologists, though, in default of other resources, they had to make use of it. As knowledge has grown the difficulties have become insurmountable to them.

First, there is its inadequacy to explain the vast amount of lateral movement required to account for the greater mountain ranges ; their rocks, originally spread over a wider area, having been folded and crushed into a narrower width. The shortening of the earth-crust thus effected has been estimated in the case of the Rocky Mountains at 29 miles, of the Himalayas at 62, the Alps at 76, and the Appalachians at the large figure of 200 miles.

Then there is the periodicity of mountain growth. The great epochs of mountain-building, such as the Caledonian, to which the chief Scottish and Welsh mountains are due, the Hercinian, responsible for the Pennine and South Wales, and the Alpine, which gave us 'the wooded, dim, blue goodness of the Weald,' were associated with vast continental development; and each was separated from the next by a period of relative inactivity lasting dozens of millions of years.

Further, there is the fact that the vigour of mountain-building, of volcanoes, and of other manifestations of unrest, has shown no sign of senility or lack of energy. The geologically recent Alpine-Himalayan range is as great, as lofty, and as complicated in structure, as were any of its precursors. The active volcanoes of Kilauea, Krakatao, or St. Pierre, and those recently extinct in Northern Ireland and the Scottish Isles, were as violent and efficient as any of those of the Palæozoic Era. The earth is 'a lady of a certain age,' but she has contrived to preserve her youth and energy as well as her beauty.

But it was when Lord Kelvin's dictum struck from geology its grandest conception, time, that it became vital to re-examine the position. He had demonstrated that, if the earth had been continuously cooling down at its present rate, its surface must have been too hot for the existence of life upon it a limited number of million years ago. The concept of geological time, indicated by Hutton in his famous saying that in this enquiry 'we find no vestige of a beginning —no prospect of an end,' had been confirmed by data accumulated through the painstaking researches of a host of competent and devoted observers all over the world. To them, familiar with the tremendous changes, organic and inorganic, that the earth had passed through since Cambrian time, it was wholly impossible to compress the life story of the earth, or the history of life upon it, into a paltry 20 or 30 million years. The slow growth and slow decay of mountain range after mountain range, each built out of, and in some cases upon, the ruins of its predecessor; the chain of slowly evolving organisms, vast in numbers and infinite in variety; told plainly of long æons of time. And the duration of these æons can be dimly realised when it is recalled that, within a small fraction of the latest of them, man, with the most primitive of implements and the most rudimentary culture, has succeeded in penetrating to the uttermost corners of the world, and developed his innumerable languages and civilisations.

Huxley, as our representative, took up the challenge in his address to the Geological Society in 1869, and asked the pertinent question "but is the earth nothing but a cooling mass 'like a hot water jar such as is used in carriages' or 'a globe of sandstone'?" And he was able to point out at least some agencies which might regenerate the earth's heat or delay its loss.

So it is only fitting that the great physicist, who imposed a narrow limit to geological time, should have prepared the way for those who have proved that the earth possesses in its radioactive substances a 'hidden reserve' capable of supplying a continuous recrudescence of the energy wasted by radiation, thus lengthening out the time required to complete its total loss. These later physicists have given us time without stint; and, though this time is the merest fraction of that envisaged by cosmogonists and astronomers, we are now so much richer than our original estimates that we are embarrassed by the wealth poured into our hands. So far from the last century's urge to 'hurry up our phenomena,' we are almost at a loss for phenomena enough to fill up the time.

The far-sighted genius of Lord Rutherford and Lord Rayleigh first saw the bearing of the rate of disintegration of radioactive substances in the minerals of rocks on the age of the parts of the earth-crust built of them. The extension and supplementing of this work by Joly, Holmes, and others, has now enabled us to look to the disintegration of uranium, thorium, and potassium, as the most promising of many methods that have been used in the endeavour to ascertain the age of those parts of the earth-crust that are accessible to observation. These methods also promise a means of dating the geological succession of Eras and Periods in terms of millions if not hundreds of thousands of years.

The decline and early death to which Lord Kelvin's dictum had condemned the earth, according so little with the vigour displayed in its geological story, is now transformed into a history of prolonged though not perennial youth. It was for

Joly, of whose work the extent, variety and fruitfulness are hardly yet fully appreciated, to take the next step and see in the release of radioactive energy a mechanism which could drive the pulse that geologists had so long felt, and that Suess had so brilliantly diagnosed. As Darwin found the missing word for Lyell, so Joly in his theory of Thermal Cycles has indicated the direction of search for a mechanism to actuate the rhythm of Suess.

In Joly's conception the running down of the earth's energy, though a continuous process, was, through the intervention of radioactivity, converted into a series of cycles, during each of which relative movements of sea and land must occur; downward movements of the continents, associated with positive encroachments of the sea; upward movements, with retreat of the sea, the formation of wide land masses, and the ridging of strata to form mountain ranges. Thus he forged a link that could unite the continental or epeirogenic movement with orogenic or mountain movement.

The visible parts of mountains and continents, as well as their lower and hidden portions, or 'roots', are made of comparatively light rocks. In order to stand up as they do their roots must be embedded in denser matter, in which they 'float' like ice-bergs in water. A far larger mass must exist below than is visible above, and the bigger the upstanding part the bigger the submerged root. Over the larger area of the ocean floor, on the other hand, the thickness of material of low density must be very slight, and the denser layer must come close to the surface.

The study of earthquakes, to which the Seismology Committee of the British Association has made outstanding contributions, has yielded, from the times taken in transmission of vibrations through the earth, the best information as to the nature and state of the interior. It has proved that the dense layer is solid at the present time. It is probably no coincidence that the earth is also but just recovering from what is possibly the greatest period of mountain-building, if not the greatest negative movement of ocean retreat, that it has ever experienced.

But solidity cannot be the permanent condition of the substratum. Heat is generated in it by its own radioactivity, but, according to the terms of the hypothesis, cannot escape, in consequence of the higher temperature generated in the continental rocks which cover it. It is therefore retained in the substratum and stored as latent heat of liquefaction, so that, within a period which has been calculated approximately in millions of years, complete melting of the sub-crust must ensue.

The resulting expansion of the liquefied stratum will have at least two effects of great importance to us. In the first place the unexpanded superficial layers will be too small to fit the swelling interior. They will, therefore, suffer tension, greater on the ocean floor than on land, and cracking and rifting will occur, with intrusion and extrusion of molten rock. In the second place the continental masses, now truly floating in a substratum which has become fluid and less dense than before, will sink deeper into it, suffering displacement along the rift cracks or other planes of dislocation. As a result the ocean waters, unchanged in volume, must encroach on the edges of the continents, and spread farther and farther over their surfaces.

Thus we have the mechanism which Suess vainly sought, causing positive movements of the oceans, their waters spreading over wide stretches of what was formerly continental land, and laying down as sediment upon it the marine stratified rocks which are our chief witness of the rhythmic advances of the sea.

This condition, however, cannot be permanent, for by convection of the fluid basic substratum, supplemented by the influence of tides within it, and the slow westward tidal drag of the continental masses towards and over what had been ocean floor, there will now be dissipation of its heat, mainly into the ocean waters, at a rate much faster than it has been or could be accumulated. Resolidification ensues, and again there are two main consequences. First, the stratum embedding their roots having now become more dense, the continental masses rise, and as they do so the ocean waters retreat from their margins and epicontinental seas, leaving bare as new land, made of the recently deposited sediments, the areas previously drowned. Secondly, the expanded crust, left insufficiently supported by the withdrawal of shrunken substratum, will suffer from severe tangential stress, and, on yielding, will wrinkle like the skin of a withering apple. The wrinkles will be mountain ranges, formed along lines of weakness such as those at continental margins; and they will be piled up and elevated to suffer from the intense erosion due to water action upon their exposed and upraised rocks.

In this, again, we have a mechanism which supplies what was needed by Suess, and one, moreover, which secures the required relationship between continental and mountain movement, between the broader extensions of continental land and the growth of mountains with their volcanoes and earthquakes and the other concomitants of lateral thrust.

Thus a Thermal Cycle may run its full course from the solid substratum, through a period of liquefaction accompanied by crustal tension, back to solidification and an era of lateral stress: and the stage is set for a new cycle.

Professor Arthur Holmes, in checking Joly's calculations, has concluded that the length of the cycles in a basic rock substratum should occupy from 25 to 40 million years, a period much too short to fit the major periods of mountain movement, as determined by him from the radioactivity of minerals contained in the rocks. On this evidence the Alpine movement should date back from 20 to 60 millions of years ago, the Hercynian 200 to 250 millions, and the Caledonian from 350 to 375 million years.

In a preliminary attempt to modify Joly's hypothesis Holmes postulated the occurrence of similar, but longer cycles (Magmatic Cycles) in a denser, ultrabasic layer underlying the basic one, the rhythm of which would be nearer to 150 million years. The shorter cycles due to the basic layer are held in part responsible for periods of minor disturbance, and also to account for the individual variations in effect, duration, and intensity of the larger ones. Each of the later movements has also evidently been limited and conditioned by the results of foregoing ones, and especially by areas of fracture and weakness on the one hand, and by large stable masses composed of rocks intensely consolidated, or already closely packed, on the other.

More recently Holmes has developed the possibility that the loss of heat is mainly due to convection in the liquid substrata, and that convection is the leading cause of the drifting and other movements of the crust, and the disturbances that have occurred in it. He says:—

'Although the hypothesis involving sub-crustal convection currents cannot be regarded as established, it is encouraging to find that it is consistent with a wide range of geological and geophysical data. Moreover, it is by no means independent of the best features of the other hypotheses. It requires the local operation of thermal cycles within the crust, and it necessarily involves contraction in regions where crustal cooling takes place. It is sufficiently complex to match the astonishing complexities of geological history, and sufficiently startling to stimulate research in many directions.'

The phenomena are difficult to disentangle as the number of operating causes has been so great and many of them are not fully understood. But, underlying them all there is unquestionably the pulse within pulse which Suess saw and of which Joly pointed the way to explanation.

The view at which we have arrived is neither strictly uniformitarian nor strictly catastrophic, but takes the best from each hypothesis. As Lyell showed, most of the phenomena of geology can be matched somewhere and sometime on the earth of to-day; but it would appear that they have varied in place, intensity, phase, and time. And, as Lyell was driven to accept *evolution* to explain the history of life on the earth, so must we employ the same word to express the life-processes of the earth itself, as was suggested by Huxley in 1869 and strongly advocated by Sollas in 1883.

The contrast in outline and structure between the Atlantic and Pacific Oceans had long been noted when Suess formulated and used the differences as the basis of his classification.

The Pacific is bounded everywhere by steep slopes, rising abruptly from profound ocean depths to lofty lands crowned with mountain ranges, parallel to its shores and surrounding its whole area. On the American side the Coast Range is continued by the Andes. On the Asiatic side chains of mountainous peninsulas and islands, separated from the continent by shallow inland seas, extend in festoons from Kamchatka and Japan to the East Indies, eastern Australia and New Zealand. This mountain ring, as Charles Lapworth said, 'is ablaze with volcanoes and creeping with earthquakes,' testifying that it has been recently formed and is still unfinished.

The Atlantic Ocean, on the other hand, is not bordered with continuous ranges, but breaks across them all: the Scottish and Welsh ranges, the Armorican range, the continuation of the Pyrenees and Atlas; and, on the American side, the uplands of

Labrador, Newfoundland and the eastern States, and the hill ranges of Guiana and Brazil. The Atlantic is in disconformity with the grain of the land, while the Pacific conforms with it. The Pacific has the rock-folds of its ranges breaking like ocean waves towards it as though the land were being driven by pressure to advance upon it, while the Atlantic recalls the effects of fracture under tension.

The middle and southern edges of the Atlantic, however, agree to some extent with the Pacific type. The Caribbean Sea, with the Antilles and the rest of its border girdle, recalls the similar structure of the Mediterranean, as it stretches eastwards, with breaks, to the East Indian Archipelago ; while the Andes are continued to Antarctica in a sweeping curve of islands. The rest of the Indian Ocean is of Atlantic type, as seen in the shores of eastern Africa and western Australia.

Another feature of the Atlantic is the parallelism of much of its eastern and western coasts, the meaning of which has often attracted the speculations of geologists and geographers. With a little stretch of the imagination, and some ingenuity and elasticity of adjustment, plans or maps of the opposite sides may be fitted fairly closely, particularly if we plot and assemble the real edges of the continents, the steep slopes which divide the 'shelves' on which they stand from the ocean depths. This has suggested the possibility that the two sides may once have been united, and have since broken and drifted apart till they are now separated by the ocean.

This view, outlined by others, has been emphasised by Wegener and dealt with by him in full detail in his work on *The Origin of Continents and Oceans*, and it now plays a leading part in what is known as the Wegener theory of continental drift. The hypothesis is supported by the close resemblances in the rocks and fossils of many ages in western Europe and Britain to those of eastern North America ; by community of the structures by which these rocks are affected ; and by the strong likeness exhibited by the living animals and plants on the two sides, so that they can only be referred to a single biological and distributional unit, the Palæarctic Region.

The hypothesis, however, did not stop at this ; and in the South Atlantic and certain other areas Wegener and his followers have also given good reasons for believing that continental masses, once continuous, have drifted apart.

Broad areas in southern Africa are built of rocks known as the Karroo Formation, of which the lower part, of late Carboniferous age, is characterised especially by species of the strange fern-like fossil plants Glossopteris and Gangamopteris. Associated with them are peculiar groups of fossil shells and fossil amphibia and reptiles. Similar rocks, with similar associations and contents, in Peninsular India have been named the Gondwana Formation. Comparable Formations also occupy large regions in Australia, Tasmania and New Zealand, in Madagascar, in the Falkland Islands and Brazil, and in Antarctica.

The correspondence between these areas is so close that Suess supposed they must at that date have been connected together by lands, now sunk beneath the sea, and he named the continent thus formed Gondwanaland after the Indian occurrences. The break-up of this land can be followed from a study of the rocks, and it was a slow process, its steps occupying much of Mesozoic time. Dr. A. L. du Toit's comparison of South African rocks with those of Brazil and elsewhere in South America favours even a closer union than this between the units now scattered.

One of the most remarkable features shown by these rocks in all the areas mentioned, but to varying extents, is the presence of conglomerates made of far-travelled boulders, scratched like those borne by the modern ice-sheets of Greenland and the Antarctic, associated with other deposits of a glacial nature, and often resting upon typical glaciated surfaces. There is no possible escape from the conclusion that these areas, now situated in or near the tropics, suffered an intense glaciation. This was not a case of mere alpine glaciers, for the land was of low relief and not far removed from sea-level, but of extensive ice-sheets on a far larger scale than the glaciation of the northern parts of the new and old worlds in the Pleistocene Ice Age. I have never seen any geological evidence more impressive or convincing than that displayed at Nooitgedacht, near Kimberley ; while the illustrations and other evidence published by David and Howchin from Australia are equally striking.

Du Toit's work on these glacial deposits brings out two remarkable facts ; first, that the movement of the ice was southerly, poleward and away from the equator, the opposite to what would be expected, and to the direction of the Pleistocene ice-movement; secondly, that the ice in Natal invaded the land from what is now sea to the north-east.

When it is realised that at this period there is no evidence of glacial action in northern Europe or America, but a climate in which grew the vegetation that formed the coal seams of our Coal Measures, it is clear that we are not dealing with any general refrigeration of the globe, even if that would produce such widespread glaciation: we are face to face with a special glaciation of Gondwanaland.

On both sides of the Atlantic these glacial episodes in Carboniferous times were followed by dry and desert climates in Triassic time, and these by violent volcanic outbursts. Nor are the rocks alike only in mode of formation, the structures by which they are traversed correspond; while even in details there is remarkable agreement, as in the peculiar manganese deposits, and the occurrence of diamonds in 'pipes' of igneous rock, both east and west of the Ocean.

Rather than face the difficulties presented by the subsidence of lands connecting the severed portions of Gondwanaland, as pictured by Suess, Wegener has preferred, and in this he is supported by Du Toit and many other geologists, to bring into contact these severed parts, which could be fitted together as nearly as might be expected, considering the dates of severance. Du Toit's map of the period places South America to the west and south of South Africa, Madagascar and India to the east, Antarctica to the south, and Australia farther to the south-east. Such a grouping would form a continent much less wide in extent than that envisaged by Suess, and would offer some explanation of the more remarkable features of the glaciation in the several areas, as well as the problems of the rocks, fossils, and structures involved.

In its application to the geology of Gondwanaland the modified hypothesis of Wegener cuts a Gordian knot; but it still leaves a great climatal difficulty, unless we take his further step and conceive that at this date the terrestrial south pole was situated within Gondwanaland. No shift in the axis on which the earth rotates would, of course, be possible, nor is it postulated: only a drifting at that date of continental land across the pole.

If a hypothesis of drift be admitted for Gondwanaland, it would be illogical to deny its application to other regions, including the north Atlantic. I have already mentioned some facts in its favour. Others are the resemblances of all sedimentary rocks on the two sides from the Cambrian to the Ordovician, and from the Devonian to the Trias; the links between the structures of the land, as, for instance, between Ireland and Newfoundland; and the instance given by Professor Bailey in his address to Section C in 1928. As Bailey then pointed out, the great Caledonian range which crosses Scotland, northern England and Wales from north-east to south-west on its course from Scandinavia is affected and displaced by the east to west Armorican (Hercynian) chain extending across from Brittany to South Wales. 'The crossing of the chains, begun in the British Isles, is completed in New England'; and from here the Armorican structure continues its westerly course. This is where it should cross if the continent of North America were brought back across the Atlantic and placed in the position which, according to Wegener, it would fit into in the European coast! Can the Pilgrim Fathers have ever dreamed of such a link between the Old England and the New?

The hypothesis of continental drift gave rich promise of solving so many difficult problems that it was hailed by many classes of investigators almost as a panacea. Geographers have seen in it an explanation of the forms of continents and the position of peninsulas, islands and mountains; meteorologists have found it the solution of some of the problems of past climates and their anomalies of distribution over the world; biologists hope to get help with the intense complexities in the distribution of forms of life and many strange facts in migration, and palæontologists with similar difficulties among the ancient faunas and floras as revealed by their fossil remains; geodesists have welcomed escape from the rising and sinking of the crust, so difficult to reconcile with the demands of isostatic equilibrium; and it has been already stated that drift forms a vital factor in Joly's thermal cycles.

But there has been no lack of criticism in all these directions. It has been assailed on the one hand for the detail attempted in its geographical restorations, and on the other hand for its vagueness. Prof. Schuchert quotes Termier as saying that it is 'a beautiful dream, the dream of a great poet. One tries to embrace it, and finds that he has in his arms but a little vapour or smoke: it is at the same time alluring and intangible.' It has been objected that 'no plausible explanation of the mechanics involved has been offered'; that the continental connexions postulated present by no means so close a match, when fitted together, as has been claimed, in the structure or the nature of either igneous or sedimentary rocks; that there is good evidence of extensive vertical movements in recent earthquakes, in the accumulation of tremendous thicknesses of sediment indicative of shallow-water from base to summit, and in the growth of coral reefs; that Central America and the Mediterranean are a difficult obstacle; and that the known distribution of the Karroo fossil reptiles is not by any means what the hypothesis demands.

If the idea of drift be accepted it cannot be regarded as a royal road out of all our difficulties, nor can it be the only form of earth-movement to be reckoned with. The late J. W. Gregory, whose life was sacrificed to geological discovery, has studied exhaustively the geological history of the Atlantic and Pacific Oceans, both as revealed by the sedimentary rocks and fossils on their borders, and by the distribution of life to-day. He finds that, according to our present knowledge, in the two oceans, facilities for migration have fluctuated from time to time, periods of great community of organisms alternating with periods of diversity. Again, at some times connexion seems to have been established north of the equator, at others to the south; and we cannot ignore the possibility of migration across polar lands or seas when terrestrial climates have differed from the present. The facts of life distribution are far too complex to be explained by any single period of connection followed by a definite breaking apart, even if that took place by stages. Mrs. Reid, too, has pointed out that resemblances between the Tertiary floras of America and Europe actually increased at the time when the Atlantic should have been widening. Unless continental drift has been a more complicated process than anyone has yet conceived, it seems impossible to escape from some form of the 'land bridges' of the older naturalists:

'Air-roads over islands lost—
Ages since 'neath Ocean lost—'

We have no right to expect greater simplicity in the life of a planet than in that of an organism.

As the question of drift must in the last appeal be one of fact, it is not unnaturally expected that the real answer will come from measurements of longitude and latitude with greater exactness and over periods longer than has yet been possible. None of the measurements hitherto made has indicated variations greater than the limits of errors of observation. Two things, however, may militate against a definite answer from this source. Many parts of the crust, such as the shield-like masses of Archæan rock, may have completed their movement, or be now moving so slowly that the movement could not be measured. Careful selection of locality is essential, and at present we have little guidance. Also, as the displacement of crust must be dependent on the condition of its substratum, it will be a periodic phenomenon and the rate of movement may vary much in time. According to the theory of thermal cycles the subcrust is at present solid, and may not permit of drift. Drift, according to Joly and Holmes, is a cyclical phenomenon; if present-day observations were to give a negative result they would not necessarily disprove it.

The occurrence of recumbent rockfolds, and nearly horizontal slides or 'nappes' in mountain regions, gives positive proof that parts of the upper earth-crust have moved over the lower. In the North-west Highlands of Scotland a sliding of at least ten miles was proved by Peach and Horne, and in Scandinavia it amounts to sixty miles. For mountain packing as a whole the figures already given are far larger, while in Asia Argand has stated that packing of over 2,000 miles has occurred. Thus, when all is said and done, movements on a colossal scale are established facts, and the question of the future is how far we shall accept the scheme of drift due to Wegener, or one or other of the modifications of it. It is for us to watch and test all the data under our own observation, feeling sure that we shall have to adapt to our own case Galileo's words 'e pur si muove'.

Ever since it was realised that the inclination and folding of rocks must be attributed to lateral or tangential stress and not solely to uplift, shrinkage of the interior of the earth from its crust has been accepted as the prime mover, and whichever of the current theories we adopt we cannot deny the efficacy of so powerful a cause.

The general course of events in the formation of a mountain range is fairly well known;

the slow sinking of a downfold in the crust during long ages; the filling of this with sediment *pari passu* with the sinking, and associated softening of the sub-crust due to accumulated heat; the oncoming of lateral pressure causing wave-like folds in the sediments and the base on which they rest; the crushing of folds together till, like water waves, they bend over and break by overdriving from above or, it may be, underdriving from below; fracture of the compressed folds and the travelling forward for great distances of slivers or 'nappes' or rock, generally of small relative thickness but of great length and breadth, and sliding upon floors of crushed rock; the outpouring and intrusion of igneous rocks, lubricating contacts and complicating the loading of the sediments; metamorphism of many of the rocks by crystallisation at elevated temperatures and under stress, with the development of a new and elaborate system of planes of re-orientation and movement; and elevation of the whole, either independently or by thickening with compression and piling up to bring about a fresh equilibrium.

Such a course of events would be brought about by lateral pressure developed during the consolidation phase of each of the thermal or magmatic cycles. At each period of their building, mountains have arisen along lines of weakness in the crust, especially coast lines and the steep slopes marking the limits between continents and ocean basins. This is consistent with Joly's theory that the thrust of ocean beds against land margins is the cause.

But the advocates of continental drift point to the siting of ranges across the paths along which the drifting movement is supposed to have occurred, and they consider that the moving masses are responsible; and indeed that the ridging and packing of the crust has in the end checked and stopped the movement. They note that the great western ranges of America occur in the path of any western drift of that continent, the Himalayas in the course of the postulated movement of India, the East Indies in front of Australia; and that the Alpine ranges of Europe may be linked with the crushing of Africa towards the north.

The 'nappes' of rock, cut off from their origin and sliding for dozens of miles, are a constant source of wonder to all who have considered the mechanics of mountain formation. They are so thin as compared with their great length and breadth, that it seems impossible to imagine them moved by any force other than one which would make itself felt throughout their every particle. Such a force is gravitation, and it is of interest that some Alpine geologists and Dr. Harold Jeffreys have used it in explanation of them. Professor Daly has also adopted gravitation on an even greater scale in his theory of continental sliding: and one cannot fail to notice the increasing use of the term 'crust-creep' by those working on earth-movement.

Is there no other force, comparable in its method of action to gravitation, but capable of producing movement of the earth-crust in a direction other than downhill? Is it not possible, for instance, that the tidal influence of the moon and sun, which is producing so much distortion of the solid earth that the ocean tides are less than they would be otherwise, and, dragging always in one direction is slowing down the earth's rotation, may exert permanent distorting influence on the solid earth itself? May it not be that such a stress, if not sufficiently powerful to produce the greater displacements of continental drift and mountain-building, may yet take advantage of structures of weakness produced by other causes, and itself contribute to the formation of nappes and to other movements of a nature at present unexplained?

Our knowledge of geology has been gained by the survey of the rocks, the study of their structures, and the delineation of both upon maps and sections. This work is being accomplished by geologists all over the world, and this country and its dependencies have contributed their full share. It is therefore opportune to note that there has just been celebrated the Centenary of the Geological Survey of Britain and, with it, the opening of the new Geological Museum at South Kensington.

A century ago H. T. de la Beche, one of the devoted band of pioneer workers then studying the geology of the country, offered to 'affix geological colours to the new maps of Devon and Cornwall' then in course of issue by the Ordnance Survey. His offer was accepted, and, at his own expense and on his own feet, he carried out a geological survey of some 4,000 square miles. In 1835 he was appointed to continue this task, with a small salary and a few assistants. Thus was started the first official geological survey, an example widely followed by other nations and dominions. De la Beche's conception included also a Museum of economic and practical geology, a Library, a Record of Mines, for which he secured support from a strong Committee of the British Association in 1838, and a School of Mines for the scientific and technical education of those to be employed in the survey or exploitation of mineral resources. In these objects, and especially the last, he was warmly supported by the Prince Consort. He lived to see his visions all come true, as he collected round himself that wonderful band of surveyors, investigators, writers and teachers, which included such men as Playfair, Logan, Ramsay, Aveline, Jukes, Forbes, Percy, Hooker and Huxley.

Some of the schemes he planned have budded off and grown into large and important entities, rendering conspicuous service to scientific record, education and research. But the main duties of the Geological Survey remained with it, and have been carried on for a century. These are to map the geology of the country on the largest practicable scale, to describe and interpret the structure of the land, to preserve the evidence on which conclusions have been founded, and to illustrate for students and other workers the geology of the country and its applications to economics and industry. The broad detail of the structure of the whole country is now known, but much new work must be done to keep abreast of or to lead geological thought. For instance, the study of the cloak of 'superficial deposits,' which often cover and conceal the structure of the more solid rocks below, is essential for the proper understanding of soils and agriculture; and a knowledge of the deep-seated geology of the country, which is often widely different from that nearer the surface and thus very difficult to interpret, is vital to the community for the successful location and working of coal and iron, and for tracing supplies of water and oil and other resources at depth.

Evolution of life on the earth has been by no means uniform; there have been periods of waxing and waning which may be attributed to geographical, climatological and biological influences. The development of large land areas, ranged longitudinally or latitudinally, the invasion of epicontinental seas, the isolation of mediterraneans or inland seas, the splitting of continental areas into archipelagoes or the reunion of islands into continuous land, the making of barriers by the rearing of mountain chains or the formation of straits or arms of the sea, the oncoming of desert or glacial climates; all such factors and many others have been of importance in quickening or checking competition, and in accelerating or retarding the evolution of life.

Probably, however, even greater effects have followed the interaction of groups of biological changes on one another. As an instance I might recall Starkie Gardner's estimate of the results following upon the first appearance of grasses in the world. This seems to have been not earlier than Eocene, and probably late Eocene times. By the Oligocene they had made good their hold, peculiarities in their growth and structure enabling them to compete with the other vegetation that then existed; and gradually they spread over huge areas of the earth's surface, formerly occupied by marsh, scrub and forest. They have, as Ruskin says, 'a very little strength....and a few delicate long lines meeting at a point. . . made, as it seems, only to be trodden on to-day, and to-morrow to be cast into the oven'; but, through their easy growth, their disregard of trampling and grazing, and by reason of the nourishment concentrated in their seeds, they provided an ideal and plentiful source of food. On their establishment we find that groups of animals, which had previously browsed on shrubs and trees, adopted them, with consequent alterations and adaptations in their teeth and other bodily structures. To follow their food from over-grazed or sun-scorched regions they required to be able to migrate easily and quickly, and it was essential for them to discard sedentary defence and to flee from threatened danger. Such defence as was possible with heels, teeth, or horns, they retained; but the dominant modifications in their organisation were in the direction of speed as their most vital need.

Side by side with this development, and in answer to increasing numbers, came bigger, stronger and speedier carnivores, to feed on prey now so much more abundant, but more difficult to catch. The answer of the grass-feeders, with their specialised hoofs, teeth and bones, better suited to flight than fight, was to seek safety in numbers, and thus develop the herd instinct, with its necessity for leadership and discipline; but this, in turn, provoked a like rejoinder from some types of their enemies.

When it is remembered how much of the

meat and drink and life of mankind is bound up with the grasses, including wheat, maize, millet and other grains, sugarcane, rice and bamboo, we must realise how close is his link with the development just outlined. Practically his whole food supply is provided by them, either directly by the agriculturist who grows little else but grasses, or indirectly by the herdsman whose domestic animals are fed chiefly on the same food. Nor must we forget that almost every one of our domesticated animals has been derived from the gregarious types just mentioned, which have accepted the leadership of man in place of that of their own species.

It is perhaps not too much to say that the magnificent outburst of energy put out by the earth in the erection of the Alps, Andes, and Himalayas in Tertiary times was trivial in its influence for man's advent and his successful occupation of the earth in comparison with the gentle but insidious growth of 'mere unconquerable grass' and its green carpet of 'wise turf' which in some form clothes by far the greater part of the land of the globe.

The kind of developmental reaction of which this is but a single example must clearly have had influence on bodily features, other than bones and horns, teeth and claws, speed and strength; and one of the most striking has been on intellectual development and the size and shape of brain.

We do not, and perhaps can never, know the quality of the material of which the brains of fossil creatures was made, for we have no instrument to pierce the veil of time as the spectroscope has penetrated the abysm of space. But we are even now learning something about their shapes and convolutions, and more about their mass in its relation to the size of the bodies controlled; from the time of the earliest Ordovician fishes, through the history of the amphibia, reptiles, birds and mammals up to man himself.

The brain of those gigantic if somewhat grotesque reptiles the dinosaurs, the tyrants of Mesozoic time, is relatively tiny. In Diplodocus, 80 feet in length and 20 tons in weight, the brain was about the size of a large hen's egg. It is true that there was a big supplementary sacral ganglion which may have taken chief charge of locomotion and helped to secure co-ordination throughout the hinder part of its huge length and bulk; but of true brain there was not more than a quarter of an ounce to control each ton of body and limb; and we begin to understand why they lost the lordship of creation.

The proportion of brain to body improved in those reptiles which took to flying, possibly in relation to their acquisition of warm blood, and in the birds evolved from reptiles; but it is only in mammals that a marked advance is seen. Here the brain of Uintatherium, a great rhinoceros-like animal of Eocene date, weighing 2 tons, was about the size of that of a dog. This proportion of half a pound of brain to each ton of body shows how far the mammals had gone, and still had to go.

A 12-stone man of the present day has about $3\frac{1}{2}$ pounds of brain—an amount not far short of half a hundredweight per ton.

Even though we can know nothing of its material, this steadfast growth in the guiding principle, through the millions of centuries that have gone to its development, is surely one of the most remarkable conclusions that we owe to geology. Of all the wonders of the universe of which we have present knowledge, from the electron to the atom, from the virus and bacillus to the oak and the elephant, from the tiniest meteor to the most magnificent nebula, surely there is nothing to surpass the brain of man. An instrument capable of controlling every thought and action of the human body, the most intricate and efficient piece of mechanism ever devised; of piercing the secrets and defining the laws of nature; of recording and recalling every adventure of the individual from his cradle to his grave; of inspiring or of ruling great masses of mankind; of producing all the gems of speech and song, of poetry and art, that adorn the world, all the thoughts of philosophy and all the triumphs of imagination and insight: it is indeed the greatest marvel of all.

And when we contemplate the time and energy, the sacrifice and devotion, that this evolution has cost, we must feel that we are still far from the end of this mighty purpose: that we can confidently look forward to the further advance which alone could justify the design and skill lavished on this great task throughout the golden ages that have gone.

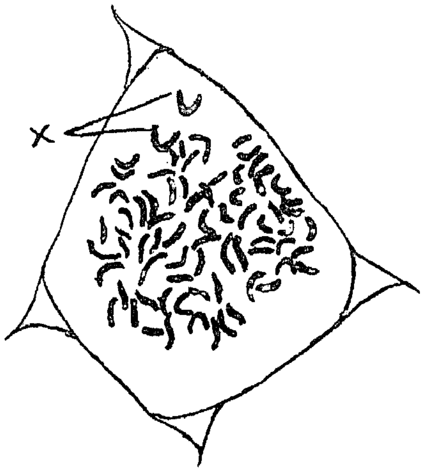

Fig 1.

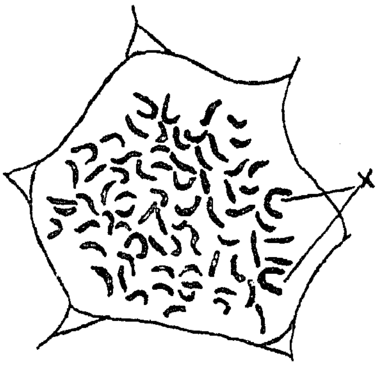

Fig 2.

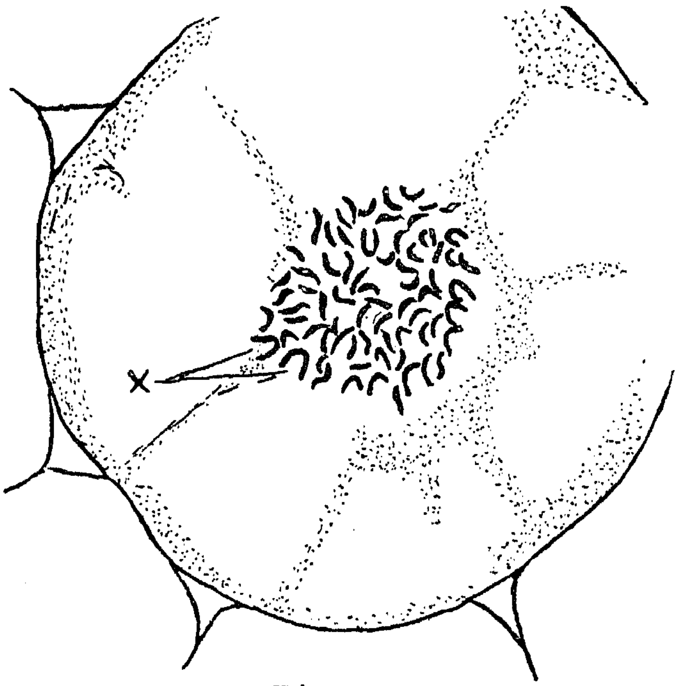

Fig 3.

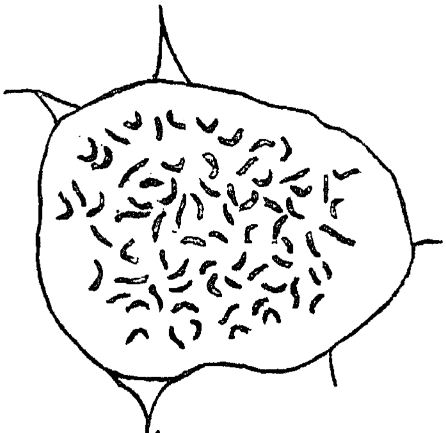

Fig 4.

Fig. 1. *H. sabdariffa* var Ruber. Fig. 2. *H. sabdariffa* Bhagalpuriensis.
Fig. 3. *H. sabdariffa* Altissima. Fig. 4. *H. cannabinus*.
U-shaped chromosomes in figures 1 to 3 marked ×.

with another maximum division phase at 11 P.M. thereby showing a periodicity in mitosis. A number of somatic metaphase plates were counted in the two species and in each case the number was found to be 72 (Figs. 1 to 4). A preliminary examination of chromosome complements in the two species revealed certain morphological differences. The chromosomes were thicker and longer in *H. sabdariffa* than those in *H. cannabinus* and in the former species there was a greater number of U- and V-shaped chromosomes (Figs. 1 to 3) while in the latter there was greater number of rod-like chromosomes.

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Rice Research Station,
Berhampore,
September 4, 1935.

* This study was undertaken by the author while he was a post-graduate student at Pusa during 1930-32.

[1] Davie, *J. Genetics*, 1934, 28, 33-67.