Dr. Rowe's account hardly does justice to the extraordinary abundance of marl in the flintless chalk. In a thickness of 32 feet there are ten seams, and three of them were noted as being of exceptional thickness.

(*To be continued in our next Number.*)

NOTICES OF MEMOIRS.

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AUSTRALIA, AUGUST, 1914.

I.—Address to the Geological Section by Professor Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S. (President of Section C).

EXACTLY eighty-three years from the day of our arrival at Sydney, Eduard Suess was born in London.[1] Thus the day, as much as the circumstances of our meeting so far from home, serves to remind us of one who was great enough to recognize the fact that geological evidence from any part of the world has the same value as that obtained in the little continent which has been the most prolific in the products of nomenclature and the most productive in textbooks.

Since the days of Charles Lyell no geologist has been so conspicuously successful in analysing the accumulated mass of evidence, in bringing together the essential facts from all lands, and in compensating for the local excesses of literature. Only those of us who, by long absence from Europe, have felt the full disadvantages of having to express our thoughts in alien terminology can appreciate the real value of Suess's great work. His death since our last meeting makes a conspicuous mark in the history of geological science.

A meeting of the British Association in Australia brings home forcibly to the members of Section C the fact that British Imperial geology is really "the science of the Earth"; partly for this reason one feels inclined to get outside the science and take a survey of some of its suburbs. Not many of them have been left untraversed by my distinguished predecessors in this chair; but there has been of recent years a tendency to avoid the inner Earth, which has rightly been described as "the inalienable playground of the imagination", and consequently, therefore, common land to the geologist as well as the geodesist, physicist, and mathematician.

The geologist who looks below the purely superficial phenomena of the crust is generally regarded as straying beyond his province; but the desire to see the birth-certificate of some of the strange and often unacceptable 'causes' which the mathematical physicist offers us is a pardonable form of curiosity. Our ideas regarding intra-telluric conditions are even proving to be of economic value, one of the most recent and unexpected results of the kind being that just established by Baron von Eötvös in Hungary,[2] whose predictions now bid fair to outstrip those of the 'diviner'! Having noticed the low gravity values over the great cores of rock-salt in the Transylvanian 'Schlier', he finds similar defects of gravity in the same region over certain of the Sarmatian and Pontian domes, which probably owe their shape to subterranean salt-plugs and are now found to be great storehouses of natural gas, which, with or without liquid petroleum, is commonly found with the saline 'Mediterranean' facies of the Upper Tertiary in Eastern Europe. Baron von Eötvös also finds that on the eastern margin of the Great Hungarian Plain, where the younger Tertiary beds are completely concealed by a mantle of alluvium, mud-volcanoes and

[1] See life of Eduard Suess, GEOL. MAG., January, 1913, pp. 1–3, and Portrait, Plate I. His obituary appeared in GEOL. MAG., June, 1914, p. 288.

[2] Comptes Rendus, XVII^{e} Conf. de l'Assoc. Géodés. Internat., Hamburg, 1912, pp. 427, 437.

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gas-springs are sometimes found in areas of marked gravity defect, and some of these are now also being drilled for natural gas.

When our ideas of the state of affairs below the surface thus begin to yield economic results, there is hope that they are at last steadying down, becoming more settled, and indeed more 'scientific'. It may not be unprofitable, therefore, to review some of the advances recently made in developing theoretical conceptions regarding the interior of the Earth that are of direct importance to geologists. In undertaking this review I am conscious of the fact that I shall be traversing ground that is generally familiar to all, and much of it the special property of specialists whose views I hesitate to summarize and should not dare to criticize. As the author of the *Ingoldsby Legends* said of the only story that Mrs. Peters would allow her husband to finish, "The subject, I fear me, is not over new, but will remind my friends—

'Of something better they have seen before.'"

The intensity and quantity of polemical literature on scientific problems frequently varies inversely as the number of direct observations on which the discussions are based: the number and variety of theories concerning a subject thus often form a coefficient of our ignorance. Beyond the superficial observations, direct and indirect, made by geologists, not extending below about one two-hundredth of the Earth's radius, we have to trust to the deductions of mathematicians for our ideas regarding the interior of the Earth; and they have provided us successively with every permutation and combination possible of the three physical states of matter—solid, liquid, and gaseous.

Starting, say, two centuries back with the astronomer Halley, geologists were presented with a globe whose shell rotated at a rate different from that of its core. In more recent times this idea has been revived by Capt. (Sir) F. J. Evans (1878) to account for the secular variations in the declination of the magnetic needle.

Clairault's celebrated theorem (1743), on which Laplace based the most long-lived among many cosmogonies, gave us a globe of molten matter surrounded by a solid crust. Hopkins demanded a globe solid to the core, and, though his arguments were considered to be unsound, his conclusions have been revived on other grounds; while the high rigidity of the Earth as a body has been maintained by Lord Kelvin, Sir George Darwin, Professor Newcombe, Dr. Rudski, and especially by the recent observations of Dr. O. Hecker, supplemented by the mathematical reasoning of Professor A. E. H. Love. Hennessy (1886), however, concluded that the astronomical demands could be satisfied by the old-fashioned molten Earth in which the heavier substances conformed to the equatorial belt.

As long ago as 1858 Herbert Spencer suggested that, on account of its temperature being probably above the critical temperature of known elements, the centre of the Earth is possibly gaseous. Late in the seventies Dr. Ritter revived the idea of a gaseous core surrounded by a solid crust, and this was modified in 1900 by the Swedish philosopher, Svante Arrhenius, whose globe with a solid crust, liquid substratum, and gaseous core is now a favourite among some geologists.

Wiechert (1897) supposed that the core of the Earth, some 5,000 kilometres in radius, is composed mostly of iron with a density of 7·8, while this is surrounded by a shell of lithoidal material having a density of about 3·0 to 3·4; and this great contrast in density is about that which distinguishes the iron meteorites generally from those of the stony class. Arrhenius also assumes that iron forms the main part of the central three-quarters, and he shows that this distribution of substance may still be consistent with his theory of a gaseous core: indeed, he not only imagines that the whole of the iron nucleus is gaseous, but also most of the siliceous shell, for he leaves only 5 per cent of the radius as the depth of the solid and liquid shells combined.

But the variety of ideas does not end with theories on the present constitution of the globe. Poisson required the process of solidification to begin from the centre and to progress outwards, while other mathematicians had been happy with the Leibnitzian *consistentior status* as the first external slaggy crust.

Since the days of Laplace all naturalists have been forced to accept the idea of a solar system formed by the cooling and condensation of a spheroidal gaseous nebula; and all except those geologists who have vainly searched for traces of the primeval crust have been happy in this belief.

Recently, however, Dr. F. R. Moulton and Professor T. C. Chamberlin in America have brought together arguments from different points of view to construct the solar system by the aggregation of innumerable small bodies, 'planetesimals,' which have gathered into knots to form the planets. Thus the Earth is supposed to have grown gradually by the accretion of meteoritic matter, and even now, although the process has nearly ceased, it receives much meteoritic material from outside.

With the Chamberlin–Moulton theory there must have been a time when the gravity of the Earth was insufficient to hold an atmosphere of any but the heavier gases, such as carbon dioxide; later, the Earth became heavy enough to retain oxygen, then nitrogen, water-vapour, and helium; while even now it may not be sufficiently attractive to prevent the light and agile molecule of hydrogen from flying off into space. With the growth of the young globe, the compression towards the centre produced heat enough to melt the accumulated fragments of meteoritic matter, and the molten material thus formed welled out at the surface. Such volcanic action is supposed to have predominated at the surface until an appreciable atmosphere was formed, and became charged with water, when the now familiar processes of weathering, erosion, and deposition produced the film of 'rust' which geologists know as sedimentary rocks.

With this last addition to the variegated array of theories about the physical condition of the Earth and about its genealogy, the scientific world began again to settle down into serenity, comforted by the happy feeling that all, at any rate, agree in regarding the Earth as a gradually cooling body, with many millions of years still before it. Then came the discovery of radium, and with it at first an assurance that geologists were justified in claiming a long past, to be followed by a longer future than the most optimistic philosopher had dared before to assume with our apparently limited store of Earth-heat. Now, however, Professor Joly warns us that if the deeper parts of the globe contain anything near the proportion of radio-active bodies found by him in the superficial rocks, we may even be tending in the other direction; that, instead of a peaceful cooling, our descendants may have to face a catastrophic heating; the now inconspicuous little body known as the Earth may indeed yet become famous through the Universe as a new star.[1]

To add to the variety of ideas regarding the present state of the Earth's interior, Professor Schwarz, of Grahamstown,[2] concludes that our volcanic phenomena can be accounted for on the assumption that the main mass of the Earth below a superficial layer is cold and solid throughout, being composed, like the meteorites, largely of unaltered ferromagnesian silicates and iron.

Thus, we see, whole fleets of hypotheses have been launched on this sea of controversy: some of the craft have been decoyed by the cipher-signals of the mathematician; some have foundered after bombardment by the heavy missiles classically reserved for use by militant geologists; others, though built in the dockyard of physicists, have suffered from the spontaneous combustion set up by an inadvertent shipment of radium. Still, some of these hypotheses are yet apparently seaworthy, and it may not be unprofitable to compare them with recently acquired data.

The nearest approach to actual observation with regard to the state of the Earth's interior has been obtained by the seismograph, designed to record the movements of seismic waves at great distances from the disturbing earthquake. Some of the waves sent forth from an earthquake centre travel through the Earth, and some travel around by the superficial crust, the former reaching the distant seismograph before the latter. The seismograph, by its record of

[1] J. Joly, *Radioactivity and Geology*, 1909, pp. 168–72.
[2] E. H. L. Schwarz, *Causal Geology*, 1910.

the waves that travel *through* the Earth, has thus given a certain amount of information regarding the state of the Earth's interior which R. D. Oldham aptly regards as analogous to that given by the spectroscope [1] with regard to the inaccessible atmosphere of the Sun.

The existence of two groups of earthquake waves—those passing through, and those passing near the surface around the Earth—has long been recognized; but R. D. Oldham [2] has shown that the waves passing through the Earth are of two kinds, travelling at two different speeds.

The record on the distant seismograph thus shows three well-marked phases: the first phase, due to waves of compression passing through the Earth's interior; the second phase, due to waves of distortion,[3] also passing through the Earth's interior; and the third phase, recorded by the waves which pass around the arc along the superficial crust.

The third phase is always recorded at a time after the occurrence of the shock proportional to the arcual distance of the recording seismograph from the earthquake centre, the records of several large earthquakes showing an average speed for the waves of about 3 kilometres per second. The rates of propagation of the waves giving the first and second phases are both much greater than of those forming the third phase; and up to an arcual distance of about 120° from the earthquake's centre the rate of their propagation increases with the distance. It is thus assumed that the waves giving rise to the first and second phases in each distant seismographic record, by following approximately along the chord of the arc between the place of origin and the instrument, pass through deeper layers of the Earth when the seismograph is farther away, the material at greater depths being presumably more elastic as well as denser.

But Oldham [4] has shown that when the seismograph is as much as 150° from the earthquake centre there is a remarkable decrease in the mean apparent rate of propagation of the waves giving the second phase in the record, from over 6 to about 4½ kilometres per second. There is also a drop, although not nearly so marked, in the apparent speed of the waves of the first phase when transmitted to a seismograph 150° or more distant from the earthquake origin. Oldham concludes that this decrease of apparent rate for waves travelling through the Earth to places much more than 120° distant is due to their passing into a central core, four-tenths of the radius in thickness, composed of matter which transmits the waves at a markedly slow speed. Thus the earthquake waves which emerge at a distance not greater than 120° from their origin do not enter this central core, while those which pass into the Earth to a greater depth than six-tenths of the radius are supposed to be refracted on entering, and again on leaving the postulated core, in which the rate of transmission of an elastic wave of distortion is very much slower than in the main mass of the Earth around. In consequence of the refraction of these waves on passing through the central core, places situated at about 140° from an earthquake origin should be in partial shadow, due to the great dispersion of the distortional waves, and the few records made so far by seismographs thus situated with regard to great earthquakes show that there is either no, or at most a doubtful, record for the second phase, which is known to be due to the so-called distortional waves.

[1] In his Presidential Address to the Geological Society of London in 1909, Professor W. J. Sollas (Proc. Geol. Soc., 1909, p. lxxxvii) credits H. Benndorf (Mitth. Geol. Ges. Wien, i, p. 336, 1908) with this pretty analogy, but Oldham has the precedence by just two years (cf. Quart. Journ. Geol. Soc., vol. lxii, p. 456, 1906).

[2] Phil. Trans., ser. A, vol. cxciv, pp. 135–74, 1900.

[3] There is more complete agreement regarding the fact that two distinct sets of waves give rise to the so-called preliminary tremors indicated by a seismographic record than about the nature of the waves. Cf. R. D. Oldham, Phil. Trans., loc. cit., and O. Fisher, Proc. Camb. Phil. Soc., vol. xii, pp. 354–61.

[4] Quart. Journ. Geol. Soc., vol. lxii, pp. 456–75, 1906.

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Oldham's deductions are based confessedly on a small number of earthquake records—he considered fourteen examples only—but the conclusions based on a small number of trustworthy records, from which variations due to the different methods of marking the phases are eliminated, are more reliable than those for which there are imperfect distant records as well as doubts regarding the exact times of the disturbances. If these observations, however, be confirmed by further records, we are justified in assuming that below the heterogeneous crust there is a thick shell of elastic material, fairly homogeneous to about six-tenths of the radius, surrounding a central core, four-tenths in thickness, which possesses physical properties utterly unlike those of the outer layers; for in this core the 'distortional' waves are either damped completely or are transmitted at very much lower speeds than in the shell.

One cannot consider this interesting inference from the seismographic data without being reminded of the contention of Ritter, Arrhenius, and Wilde regarding the possibility of a persistent gaseous core still above the critical temperature of the substances of which it is composed. According to Ritter,[1] the gaseous core is surrounded by a solid shell. Dr. Wilde[2] postulates the existence of a liquid substratum and a gaseous core within a solid crust, the two outer shells having a thickness that is 'not very considerable'. Arrhenius assumes from purely physical considerations that the solid crust is only about 25 miles thick, that below this it is possibly in a molten condition for about 150 miles, and that the rest is a gas largely composed of iron under a pressure so great that its compressibility is not much less than that of steel.

The whole of these conclusions, being based on assumptions regarding the physical properties of matter under conditions of temperature and pressure that are well beyond those of actual experience, must be put on a plane of science well below that occupied by the investigations initiated by Oldham, who opens up a line of research in which, as said before, the seismograph may justifiably be compared with the spectroscope as an instrument for observing some inaccessible regions of Nature.

The mathematician apparently finds it just as easy to prove that the Earth is solid throughout as to show by extrapolation from known physical values that it must be largely gaseous. As Huxley said in his Presidential Address to the Geological Society in 1869, the mathematical mill is a mill which grinds you stuff of any degree of fineness, but, nevertheless, it can grind only what is put into it; and the seismograph thus offers a new source of substantial grist. Now that it is fairly certain that some of the earthquake waves pass through the deeper parts of the Earth, it is obvious that a fruitful development of science will follow successful efforts to introduce precision in recording, and uniformity of expression in reading, seismographic records.

Oldham[3] has pointed out another way in which analysis of seismographic records may lead to information regarding intra-telluric conditions by comparing the records of waves that pass under the oceanic depressions with those that are sub-continental for the whole or most of their paths. By comparing the records in Europe of the Columbian earthquake of January 31, 1906, with those of the San Francisco quake in the following April, there was a greater interval

[1] A. Ritter, "Untersuchungen über die Höhe der Atmosphäre und die Constitution gasformiger Weltkörper": Wiedemann's *Ann. d. Phys. und Chem.*, vol. v, pp. 405, 543, 1878; vol. vi, p. 135, 1879; vol. vii, p. 304, 1879; vol. viii, p. 157, 1879.

[2] *On the Causes of the Phenomena of Terrestrial Magnetism*, pamphlet, 1890, p. 2. The idea that the Earth's magnetism is due to the electricity generated by the friction between the shell and the core, rotating with a different motion, was suggested by Dr. Wilde in 1902 (Mem. Manch. Lit. Phil. Soc., vol. xlvi, pt. iv, p. 8, 1902). A similar suggestion based also on Halley's conception of a separately rotating inner core was made previously by Capt. (Sir) F. J. Evans in 1878 ("Remarkable Changes in the Earth's Magnetism": *Nature*, vol. xviii, p. 80).

[3] Quart. Journ. Geol. Soc., vol. lxiii, pp. 344–50, 1907.

noticed between the first and second phases of the Californian earthquake—an interval greater than can be accounted for by mere difference of distance between the origin of the shock and the recording instruments. The seismic waves which passed from Columbia to Europe must have travelled under the broadest and deepest part of the North Atlantic basin, while those from California ran under the continent of North America, crossed the North Atlantic not far south of Iceland, and approached Europe from the north-west, the wave paths throughout being under continents or the continental shelf of the North Atlantic. There is thus suggested some difference between the elastic conditions of the sub-oceanic and the sub-continental parts of the crust—a difference which, judging by the particular instances discussed, may extend to a depth of one-quarter of the radius, but is not noticeable in the waves which penetrate to one-third of the radius below the surface.

Obviously these data must be multiplied many times before they can be regarded as a reliable index to a natural law; but it is significant that this indication of a difference between the physical nature of the sub-oceanic and sub-continental parts of the crust is in rough correspondence with the conclusions previously suggested on quite other grounds.

In his Presidential Address to the Geological Section of the British Association at Dover in 1899, the late Sir John Murray drew attention to the chemical differentiation which has been going on between the continents and the oceans since the processes of weathering and denudation commenced. By these processes the more siliceous and specifically lighter constituents are left behind on the continents, while the heavier bases are carried out to the ocean. It is to this process that Professor T. C. Chamberlin[1] also ascribes the origin of the depressions in which the oceanic waters have accumulated. As a corollary of the planetesimal theory, Chamberlin assumes that water began to be forced out of the porous surface blocks of the accumulated meteoritic material when the Earth's radius was between 1,500 and 1,800 miles shorter than it is now; at that time pools of water began to be formed on the surface, and the atmosphere, just commencing its work, began the operation of leaching the heavier bases out of the highlands. Growth of the world proceeded by the infall of planetesimals, and while those meteorites that fell on the highlands became deprived of their soluble bases, those that fell into the young ocean were merely buried unaltered. Thus by the time the Earth reached its present size its crust under the oceanic depressions must have developed a chemical composition differing from that under the continents. According to the deduction suggested by Oldham from the seismographic records, there is a noticeable difference in the sub-oceanic areas to depths of between 1,000 and 1,300 miles—a layer in which the followers of Chamberlin's theory might reasonably expect some physical expression of the partially developed chemical differentiation.

The occurrence of denser material below the ocean has, of course, long been assumed from the deflection of the plumb-line, and was accepted by Pratt for his theory of compensation, as well as by Dutton as a wide expression of the theory of isostasy. Chamberlin[2] thus explains the general prevalence of basic lavas in oceanic volcanoes.

The apparent heterogeneity indicated in the outer shell of the Earth to depths of 1,000 miles is naturally in conflict with the assumption that from 30 miles or so down the materials are in a liquid condition; at any rate, the idea conflicts with Fisher's extreme conception of the liquid substratum, in which the fluidity is supposed to be sufficient for the production of convection currents, upwards beneath the oceanic depressions, spreading horizontally towards the continents, and thence downwards to complete the circuit.

The idea that changes of azimuth and of latitude may be brought about by the sliding of the Earth's crust over its core has been put forward more than

[1] Chamberlin and Salisbury, *Geology*, vol. ii, pp. 106–11, 1906.

[2] *Geology*, vol. ii, p. 120, 1906.

once to account for the climatic changes of past geological ages—the occurrence of temperate or even warm climates on parts of the crust now within the Polar circles, and glacial conditions at the sea-level in countries like India, Australia, Africa, and South America, which are now far from the Polar ice-sheets and in some cases near or within the Tropics. Professor E. Koken, of Tübingen,[1] in an elaborate memoir entitled *Indisches Perm und die Permische Eiszeit*, attributes the idea of a sliding crust to Mr. R. D. Oldham; but a similar suggestion was put forward by the late Sir John Evans twenty years before the publication of Mr. Oldham's paper,[2] and when the theory was restated in more precise form, ten years later,[3] it was subjected to mathematical criticism by J. F. Twisden, E. Hill, and O. Fisher.[4]

Sir John Evans suggested that this movement of the crust was inevitable as a consequence of the moulding of the orographical features and consequent redistribution of weights; but Twisden came to the conclusion that the re-arrangement of the great inequalities on the Earth's surface would be insufficient to produce any appreciable sliding of the order required to make material differences in the climate of any place.

Oldham,[5] who was writing at the time in the field in India and thus away from literature, put forward the idea in 1886 as an independent thought, and made use of Fisher's new theory regarding the existence of a fluid stratum between the solid crust and the supposed solid core to account for the shifting of places relative to the axis of rotation from the equatorial region even to the Polar circles. Oldham drew attention to the recorded small changes of latitude at certain observatories and to the probable changes of azimuth in the Pyramids of Egypt—evidences of a kind which have since been greatly enlarged by the work of Sir Norman Lockyer and others.

The movements assumed to have taken place during the human period are of course small; and to project from them changes as great as the transfer of lands from the Polar circle to the Tropics has the objection that characterizes a surveyor's use of 'unfavourable' triangles in a trigonometrical survey. Before admitting, therefore, that these small changes of latitude and of azimuth may be classed with the palæo-glacialists' evidence as data of the same kind, though so utterly different in magnitude, it is desirable briefly to examine the geological evidence regarding past ice ages in extra-polar areas.

From the records of ancient glaciations we might omit those of the pre-Cambrian rocks of North Ontario and the pre-Upper Cambrian of Norway, as these areas are nearer the Poles than many places which were certainly covered with ice-sheets during the youngest, or often so-called Great, Ice Age. But besides these we have evidence of glaciation in the Cambrian or possibly pre-Cambrian rocks of South Australia at a latitude of 35° or less; in South Africa there were two or more distinct glacial periods before Lower Devonian times in slightly lower latitudes; while in China similar records are found among rocks of the Lower Cambrian, or possibly of older age, at a latitude of 31° N.

The glacial boulder-beds found at the base of our great coal-bearing system in India belong to the same stratigraphical horizon as the glacial beds found in South Africa, certain parts of Australia, and in parts of Brazil and São Paulo near or within the Southern Tropic.

[1] *N. Jahrb. für Min. u.s.w.*, p. 537, 1907.

[2] J. Evans, "On a possible Geological Cause of Changes in the Position of the Axis of the Earth's Crust": Proc. Roy. Soc., vol. xv, p. 46, 1866.

[3] J. Evans, Presidential Address, Proc. Geol. Soc., 1876, p. 105.

[4] J. F. Twisden, "On possible Displacements of the Earth's Axis of figure produced by Elevations and Depressions of her Surface": Quart. Journ. Geol. Soc., vol. xxxiv, p. 35, 1877. E. Hill, "On the possibility of Changes in the Earth's Axis": Geol. Mag., 1878, pp. 262, 479. O. Fisher, "On the possibility of Changes in the Latitude of Places on the Earth's Surface": Geol. Mag., 1878, pp. 291, 551.

[5] Geol. Mag., 1886, p. 304.

These glacial beds are often referred to in the geological literature as Permo-Carboniferous in age; but Professor Koken regarded the formation in India as Permian. Other valuations of palæontological evidence, similar to that relied on by Professor Koken, place these beds at a distinctly lower horizon in the European stratigraphical scale, and recent work by officers of the Geological Survey of India in Kashmir tends to confirm this latter view; we now regard the base of our great coal-bearing system in India—the horizon of the glacial boulder-beds—as not much, if at all, younger than the Upper Coal-measures of Britain.[1] The precise age of the horizon is not very important for our present consideration: the important point is that in or near Upper Carboniferous times a widespread glaciation occurred throughout the area now occupied by India, Australia, and South Africa. The records of this great glaciation are thus found stretching northwards beyond the northern as well as southwards beyond the Southern Tropic.

Now, on the assumption that the cold climate in this region was due to a movement of the crust over the nucleus, Professor Koken has produced an elaborate map of the world, showing the distribution of land and sea during the period, with the directions of ocean currents and of ice-sheets. The Permian South Pole he places at the point of intersection of the present 20th parallel S. and 80th meridian E.—that is, at a point in the Indian Ocean about equidistant from the glaciated regions of India, Australia, and South Africa. The Permian North Pole is thus forced to take up its position in the centre of Mexico, while the Equator strikes through Russia, Italy, West Africa, down through the South Atlantic and round by Fiji to Vladivostock.

The very precision of this map reduces the theory on which it is based to a condition of unstable equilibrium. If glacial conditions were developed in India, Australia, and South Africa by a 70° movement of the crust, were the movements to and from its assumed position in Permian times so rapid that the glaciation of these widely separated areas appear to be geologically contemporaneous? If such movements had occurred, instead of evidences of glaciation over a wide area at the *same* period, we ought rather to find that the glaciation in each of the widely separated points occurred during distinctly *different* geological periods.

But that is not the only weak spot in the evidence. The Permian (or Permo-Carboniferous) glaciation of Australia took place on the east and south-east of the continent as well as in Western Australia, and the eastern ice-sheets would thus have been active within 30° of Professor Koken's Permian equator. There are still three other serious pieces of colour-discord in this picture. In the State of São Paulo—that is, within Koken's 'Permian' tropics—Dr. Orville Derby has described beds which strikingly recall the features of the Upper Palæozoic glacial beds of India and South Africa. It is possible that these are due to the work of glaciers at a high level; but, since the publication of Professor Koken's memoir, other occurrences of the kind have been described by Dr. I. C. White in different parts of Brazil, and there is a general correspondence between the phenomena in South America and those in the formations of the same age in the Indian, Australian, and African regions.

Then, too, if we accept this expression of the physical geography during Upper Palæozoic times, we must carefully explain away the suspicious breccias and brockrams which have been regarded by many geologists as evidences of a cold climate during Permian times in the Urals, the Thüringerwald, the English Midland and Northern counties, Devonshire and Armagh—places that would lie on or near Koken's 'Permian' equator. Finally, we find the hypothetical Permian North Pole in a locality which has failed to produce any signs of glaciation.

(*To be concluded in the October Number.*)

[1] H. H. Hayden, Rec. Geol. Surv. Ind., vol. xxxvi, p. 23, 1907.

II.—*Papers read in Section C (Geology), Meeting of British Association, Australia, August, 1914.*

(1) Deserts (Definition, Causes, and Soils). By Professor J. W. Gregory, F.R.S.

THE term 'desert', according to modern usage, means a country which is unoccupied in consequence of having an arid climate. Various exact limits of the conditions that established deserts have been proposed. Thus Sir John Murray adopted the desert limit as a 10 in. rainfall, and William Macdonald (*Dry Farming*, p. 91, 1911) that of 20 inches as the limit of the arid region. Goodchild, on the other hand, rejected numerical limits as arbitrary and impracticable, and proposed a more elastic definition based upon a general deficiency of moisture. Walther has pointed out that deserts cannot be precisely defined on biological, morphological, or climatic grounds.

The factors that control the development of desert are not only climatic. The geological structure of the district has an important influence. The presence of rocks which are very permeable owing to porosity of jointing, and which crumble into coarse grains, contributes to desert conditions. Geographical situation is also important, for a plateau which has a free drainage to adjacent lowlands is more easily converted into desert than an area with no easy escape for its subterranean water.

The climatic influence depends not only upon the total amount of rainfall but upon its distribution through the year. Thus a country where the rainfall is in the late summer and autumn may be economically desert, whereas the same rainfall at a more suitable season would render the country fertile. The Transvaal, for example, is hampered by its only certain rains falling between November and March. Temperature and the complex group of factors which determine the rate of evaporation also have an important influence.

Hence the development of desert is not determined by any rigid minimum of rainfall, but by the balance between the many conditions which govern the utilization of the rain.

Deserts are most easily produced and least curable where the rainfall is low, the temperature is high, the wind is strong, and the country consists of a plateau where there is an easy drainage to the adjacent lowlands. On a high plateau the elevation, by lowering the temperature and cooling the air uplifted on to it, tends to secure rain, though if it easily drains to the lowlands the main value of the rain may be on them.

Proximity to the sea is quite consistent with a desert development, for if the sea-water be colder than the land, the capacity of the air for moisture is increased as it blows ashore and a sea-wind may therefore act as a drying and not as a moisture-carrying agent.

Desert and non-desert conditions have frequently alternated in the same district. Thus in the British area there is evidence that desert conditions prevailed during the times of the Torridon Sandstone, the Old Red Sandstone, the Permian, the Trias, and there is evidence of an arid climate in Ireland during part of the Lower Kainozoic. It has

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been suggested that the existing deserts are now increasing, but the evidence (recently summarized in the *Geographical Journal*, vol. xliii, pp. 148–72, 293–318, 1914) indicates that there has been no general expansion of the desert areas, which are, however, in some places shifting their positions in consequence of local climatic changes.

Deserts are not absolutely incurable, and, owing to a better knowledge of how to use their slight and irregular rainfall, many once-desert areas are now in profitable occupation. When suitably watered, deserts may be extremely prolific; for their soils are often rich in immediately available plant-foods which have accumulated during the long period of rest. The desert soils are often very deep and their crops are nourished from an unusually thick layer. The desert soils especially accumulate salts of potash and lime, which would be leached out of them with a heavier rainfall.

Australian soils have as a rule less than the usually accepted minimum of phosphoric acid required for cultivability. Thus, according to the analyses collected by Professor Cherry, English soils have ·098 per cent of phosphoric acid, American ordinary soils ·116, and American clay soils ·207; yet the heavier soils of Victoria have only ·06 and the light soils of the mallee only ·047.

Professor Cherry's results are confirmed by a varied series of 267 soil analyses from Germany, Holland, Spain, Hungary, Jersey, Sweden, Russia, Java, Sumatra, India, Sandwich Isles, the Congo, the Cameroons, Senegambia, German East Africa, South Africa, and Madagascar. The number includes 22 British and 57 from various outlying parts of the United States of America. In these 267 analyses the average of phosphoric acid is ·157 per cent.

Most soils contain more phosphoric acid in the soil than in the subsoil—an advantage which Australian soils do not share. A series of 220 analyses, collected for me by my assistant, Mr. P. Brough, which show the composition of various soils and their subsoils, give an average of ·158 of phosphoric acid in the soil and ·135 in the subsoil; and, excluding a couple of subsoils in which the result is so high that there must be an inclusion of some phosphatic fragment, the ratio of phosphoric acid in soil to subsoil is 16 to 13. In some cases the soil may owe its excess of phosphoric acid to manure; but the excess is often shown in cases in which the land has not been manured.

This series of analyses confirms the generally accepted fact that Australian soils are exceptionally low in phosphate and that outside Australia the soil is usually more phosphatic than the subsoil.

The only explanation of these two abnormal features of Australian soils that appears at all satisfactory is that proposed by Professor Cherry; according to his interpretation the phosphatic accumulation in the soil is due to the action of mammals, and owing to the poverty of Australia in mammalian life no such phosphatic enrichment of the soil has taken place. Soils, therefore, in Australia, which appear to be incurably barren, may, owing to their other excellent qualities, prove of high value if their poverty in phosphoric acid be remedied by manure.

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(2) Note on the Occurrence of Loess Deposits in Egypt and its Bearing on Change of Climate in Recent Geological Times.[1] By H. T. Ferrar, M.A., F.G.S.

AT a recent meeting of the Association Dr. Hume and Mr. Craig submitted the view that there had been no change, except that of gradual desiccation, in recent geological times in Egypt. Since their paper was published, evidence that the change of climate has not been uniform has been recorded from neighbouring countries. The following short paper is intended to show how Æolian desertic deposits may be interstratified between freshwater beds without any change of climate.

In the northern delta of Egypt are great stretches of flat land a few feet above sea-level. These areas are covered by ordinary Nile alluvium and remain damp during the winter months but dry in summer. Owing to the evaporation which takes place during the spring and early summer, soluble salts accumulate at or near the surface of the soil, rendering it incoherent and powdery. Winds are now able to lift and transport this material until it is arrested by the roots of halophyte plants or other obstacles. Here also are deposited the dead shells of helices, and occasionally also the remains of land animals, such as the jackal, rat, bird, lizard, or snake, which have been seen frequenting dust-dune areas. In fact, the dust dunes of Northern Egypt, known as Kardud to the inhabitants, are local deposits of Loess.

A depression of the land of only a few feet, and such as that which has taken place since Roman times in Egypt, would cause another fluviatile layer containing the common shell *Cyrena fluminalis* or a lacustrine bed to be superimposed upon them. It is thus manifest that a desertic deposit interstratified between two freshwater beds is not necessarily a proof of change of climate.

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(3) The Physiography of Arid Lands (as illustrated by Desert Egypt). By W. F. Hume, D.Sc., F.R.S.E., A.R.S.M., Director Geological Survey of Egypt.

THE characters of an arid land cannot be separated from its past history, and in Egypt five physiographic features of first importance have to be considered. These are—

1. A belt of deep impressions in the extreme west, the famous Oases.

2. The broad waterless expanse of the Western or Libyan Desert, to the west of the Nile, and the corresponding limestone plateau region (the Maaza Limestone Plateau) to the east of the river.

3. The Nile Valley with its Delta.

4. The Wilderness of the Red Sea Hills and Sinai with its rugged mountains and tortuous valleys.

5. The Red Sea and its narrow prolongations, the Gulfs of Suez and Aquaba, together with the coastal plains.

Each of these divisions requires separate treatment. The paper

[1] By permission of the Director-General of the Egyptian Survey Department.

gives a rapid sketch of the geological history of Egypt as known to us at present, the formation of the ancient core of pre-Cambrian or Palæozoic sediments, volcanic rocks with invasion by granitic magmas, the brief Carboniferous marine advance, and later the much more important Jurassic-Cretaceous transgression, which practically affected almost the whole of Egypt, giving rise to the Nubian Sandstone and the important phosphate-bearing Cretaceous Series. The Eocene strata which form the major portion of Central Egypt are probably formed, at the base, of remade Cretaceous material, and only in their upper portions show marked evidence that the underlying sandstones and igneous rocks are undergoing erosion.

The re-arranging of Cretaceous strata eroded during Eocene times is regarded by the writer as explaining the great difficulty experienced in drawing a lithological line of unconformity between the beds of these respective periods, though the faunal differences indicate the great break between them.

Fringing the pre-Eocene and Eocene areas of Egypt are a series of Miocene and more recent formations which are of great interest both from tectonic and economic points of view.

In considering the separate physiographic features it is pointed out:

1. In the formation of the Oases it is necessary to consider the denudation of the area by marine erosion while rising from the sea and the effects of former more humid climatic conditions. Where the Nubian Sandstone or other soft beds have been exposed, as Beadnell has pointed out, the Oases depression without outlet is produced by wearing through wind-blown sand.

2. The Great Plains of the Libyan Desert are regions of low dip, of meagre rainfall, and thus wind is the dominant factor. A sandy region to the north supplies the sand necessary for erosion. The character of the desert surface depends on the nature of the geological strata present. The undulating gravel plateaux, or *serir*, the limestone expanse, the 'melon' country, and the fossil floors are various forms in which the desert presents itself, the main feature being the removal of all particles capable of being transported by wind. These are deposited as sand-falls in the wind-shadows of the Nile Valley scarp or other depressions. The sand dunes which are locally developed are in sharp contrast to the main desert, these probably depending on three main factors—the existence of sandy deposits determining their source of origin, the usual direction of the wind their trend, and the relief of the ground their position.

The Maaza Limestone Region is similar to the Libyan Desert, but has a greater rainfall. It thus presents a fine example of the effects when rain acts during short periods on rock-surfaces affected by temperature variations. Deep ravines, remarkable water-holes, caverns, natural bridges, and surface coloration films due to the trickling down of ferruginous solutions over cliff-walls are among the prevailing features in the southern part of this area.

3. The present course of the Nile Valley appears to depend on three factors: (1) the formation of the syncline, the axis of which it partly follows; (2) the erosion of the softer strata along their outcrops determining the present north–south trend of the major courses

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of the river; and (3) the possible effect of the rotation of the earth (Van Baer's law), the stream tending to hug its eastern bank. Attention is called to the region of exceptional erosion where heavy masses of Eocene limestone rest on and have slipped over the subjacent soft Cretaceous marls and slates. These slips must have been connected with greater rainfall and earth-movement as widespread terraces extend in front of the main cliff and rise to some 110 metres above the present river-level. The triple terracing of the Nile is briefly considered.

4. The Mountain Region of the Eastern Desert is essentially an Anticlinal Area, where tension is in excess of compression. The differential movements are considerable, minor folds play a conspicuous part, and great fractures determine earth-features of considerable magnitude. The result is that the masses of granite and metamorphic rocks hidden beneath the surface in Central Egypt are here exposed by denudation, forming the Red Sea Hills and Sinai Mountains.

The different geological formations give rise to very varied surface features. Attention is called to the importance of rain as a sculpturing agent. The soft Nubian Sandstone is easily eroded both by windborne sand and water, giving rise to conspicuous depressions. In the Granitic areas temperature variation breaks up the solid rock, huge domes are produced by flaking off of concentric shells. Dykes give rise to marked differences in surface outline, the harder quartz-porphyries determining the form and general trend of many of the mountain summits, while the softer diabases, being easily eroded, give rise to gullies seaming the precipitous sides of the granitic hills. The general character of the country where schists and volcanic rocks are present is also described.

5. In the Gulf of Suez area another factor has come into play. Here sea-arms project far inland between land-surfaces subject to desert conditions, and their waters become centres of far-reaching chemical activity. Thus coral-reefs are changed to dolomites, sea-shells of carbonate of lime to gypsum, hydro-carbons are in quantities of economic importance, and mineralized areas of lead and zinc ores, of manganese oxide, of iron pyrites, and of sulphur are present in the young Tertiary beds which fill these Red Sea depressions. From Suez to beyond Halaib, that is, throughout the length of Egypt, gypsum forms a conspicuous fringe between the ancient hills and the sea, generally dipping gently seaward on the borders of the Red Sea itself. Further north, in the Gulf of Suez area, the conditions are more complicated. Dyapir, or piercing folds such as have been described by Professor Mrazec in Roumania, are of common occurrence, and there is remarkable interplay between the hard and soft members of the folded series.

The surface structure of an arid land is not only the direct reflex of its geological structure, but also of former climatic change. Many factors in Egypt point to great rainfall in the past, such as gravels of igneous material in the Nile Valley far from their source of origin, masses of travertine in the Oases, the varying terraces of the Nile Valley itself, the evidence of expansive lakes at Kom Ombo, etc.

Though the main features of a desert land depend on the geological structure and in part on past climatic conditions, there are characteristics which are typical of all arid regions. These are far removed from the great marine areas and from the zone of rainfall dependent upon solar activity in lands beneath the Tropics.

These typical desert features have already been referred to, and include—

1. The sweeping of all fine material from the surfaces of the plains by the action of the wind, and formation of plateau summits.
2. Intense scouring of these surfaces by wind-driven sand.
3. The breaking up of the most solid rocks by temperature variation.
4. The formation of sand dunes behind obstructions or where the relief of the ground favours their development.
5. The formation of mushroom-shaped pillars, or standing-out of harder materials on bases undercut by the sand.
6. The formation of sand-worn pebbles of typical angular outlines, the well-known Dreikante.
7. Vermicular markings on limestones, due it may be to etching during the movement of evaporating saline solutions.
8. Formation of desert-crusts by leaching out of the soluble materials contained in the rocks, with evaporation at the surface, resulting in deposition of the oxides of iron and manganese. Mr. Lucas, Director of the Survey Department Laboratory, has made a special study of these desert and river films, the latter probably only differing from desert ones in degree.
9. Flaking off of surfaces in the surface zone affected by temperature variation. Also fracture due to the same cause. Fragments of porphyry, limestone, etc., are often split into a series of parallel flakes standing vertically, their original connexion to one another being clearly indicated by their close juxtaposition.

In the half-desert where rain, though brief, is intensely active while it lasts, a series of interesting phenomena are presented: deep cañon-like valleys, boulder-strewn gullies, saw-back ridges, parallel-dyke country, saline marshes, dry waterfalls or steep precipices in the valley-floors, great talus-slopes.

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(4) The Denudation of Arid Regions by Wind and Water. By Johannes Walther, Professor of Geology and Palæontology in the University of Halle, Germany.

EVERY climatic region is characterized by a different type of disintegration and denudation of soft or softened rock by the agents of erosion. In the nival region a cover of snow protects the surface of the earth during a long period of the year.

In the humid zone and also in the equatorial pluvial region the soil is overgrown by a network of roots and rootlets of millions of plants, which bind together the small particles and protect them against wind and running water.

In arid regions, where the rain is not sufficient to form perennial rivers, and where the vegetation forms isolated patches in the barren country, every particle of soft or disintegrated rock is quickly taken away by the wind or the occasional rainfall. Therefore the general denudation of the land is very powerful. The Egyptian monuments, exposed during 4,000 years to the disintegrating and denuding powers of the desert, offer beautiful examples of the different kinds of dry disintegration, and many of them show very clearly also the transporting effect of the wind.

REVIEWS.

I. — W. W. Nikitin. La Méthode Universelle de Fedoroff. Traduction française par L. Duparc and Mlle V. de Dervies. Two volumes in one; pp. 516 and atlas. Genève, Edition Atar; Paris, Béranger. 30 francs.

THE universal or theodolite methods of investigating the geometrical and optical properties of crystals were first fully described by Professor Fedoroff in the year 1893. The problems connected with the geometrical study are relatively simple, and the original theodolite or two-circle goniometer scarcely admitted of any essential improvement. On the other hand, the full determination of the more important optical constants of a crystal fragment or of a mineral in thin section obviously presents difficulties of a far higher order, which have only been successfully surmounted after the expenditure of much time and ingenuity on the part of the creator of the method and of his pupils, amongst whom the author of the present work must always take the highest place. The employment of the Fedoroff universal stage in its present perfected form cannot fail to revolutionize the optical study of crystals, not merely by reason of the fact that a mineral can be identified with great rapidity, but because it is now possible to determine optical constants with such a high degree of exactitude as to settle within narrow limits the position of the mineral in its isomorphous group. This is especially true of the felspars, the optical data of which have been so extensively and carefully studied.

The work is a translation with many important additions of a comprehensive guide to the use of the universal stage, which was especially written by Professor Nikitin for the use of the students in the St. Petersburg School of Mines. Its scope may be best indicated by the following table of contents:—

Tome i: Introductory chapter on the optical properties of crystals, pp. 1–59. Graphical methods, especially those relating to the use of the Fedoroff stereographic net, pp. 60–91. Description of the universal stage and its adjustment on the polarizing microscope, pp. 92–120. Discrimination of optically isotropic, uniaxial, and biaxial crystals, pp. 121–39. Determinations of the orientation and optic axial angle of a biaxial crystal, pp. 140–89. Approximate determination of the refractive index, 190–237. Recapitulation of methods for a biaxial crystal, pp. 238–49. Uniaxial crystals, pp. 250–69.

Tome ii: Determination of the thickness of the section and of the birefringence, pp. 275–443. Determination by extinction methods of

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