invariably to thickness of chalk, not length of exposure; and though it is possible that the phrase is here intended to refer to length of exposure, not thickness of chalk, that theory can hardly be reconciled with the contrast he draws (p. 28) between *M. pumilus* found "close to the sluice" and a form of *Echinocorys* found "near the base of the zone". The point is one of some importance, for if the chalk exposed is *in situ* right up to the stream the strike corresponds so nearly with the direction of the bank between the cascade and the stream that not more than 30 feet of chalk at the outside can be brought in in this distance. A specimen of *M. pumilus* found even at the very edge of the stream would then occur practically at the base of the zone, which is completely at variance with all my experience elsewhere; even the 150 feet of *mucronata* chalk in Whitecliff Bay, and the 196 feet in Scratchells Bay have only yet yielded me one specimen each. But if this chalk is not *in situ*, then the occurrence of *M. pumilus* in it is immaterial in considering the downward range of that fossil. Further, if there is no *mucronata* chalk *in situ* at the foot of the cliff Barrois' reference of the chalk of the west side of Arish Mell to his zone of *Marsupites* is not open to the criticism Dr. Rowe levels at it; for it is abundantly clear that Barrois' zone of *Marsupites* embraced the greater part, probably the whole, of the old zone of *A. quadratus*.

(*To be concluded in the November 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).

(*Concluded from the September Number, p. 418.*)

TO attempt a discussion of the explanations offered to account for the great Upper Palæozoic glaciation would lead us far from the present theme. The question is raised merely to show that the phenomena are not consistent with the supposed movement of a solid shell over a solid core assisted by an intermediate molten lubricant. Geologists may be compelled to hand back the theory of a molten substratum to the mathematicians and physicists for further repair; but it does not necessarily follow that a foundation theory is unsound merely because it has been overloaded beyond its comprehensive strength.

The extraordinarily great distances between the areas that show signs of glaciation in Permo-Carboniferous times form a serious stumbling-block to most of the explanations which have hitherto been offered. One is almost tempted in despair even to ask if it is not possible that these fragments of the old Gondwana continent are now more widely separated from one another than they were in Upper Palæozoic times. It is a bold suggestion indeed that one can safely put aside as absurd in geomorphology. There is nothing else apparently left for us but the assumption of a general refrigeration.

The idea of the greater inequalities of the globe being in approximately static equilibrium has been recognized for many years: it was expressed by Babbage and Herschel; it was included in Archdeacon Pratt's theory of compensation; and it was accepted by Fisher as one of the fundamental facts on which his theory of mountain structure rested. But in 1889 Captain C. E. Dutton presented the idea "in a modified form, in a new dress, and in greater detail"; he gave the idea orthodox baptism and a name, which seems to be necessary for the respectable life of any scientific theory. "For the condition of equilibrium of figure, to which gravitation tends to reduce a planetary body, irrespective of whether it be homogeneous or not," Dutton[1] proposed "the name *isostasy*". The corresponding adjective would be isostatic—the state of balance between the ups and downs on the Earth.

For a long time geologists were forced to content themselves with the conclusion that the folding of strata is the result of the crust collapsing on a cooling and shrinking core; but Fisher pointed out that the amount of radial shrinking could not account even for the present great surface inequalities of the lithosphere, without regard to the enormous lateral shortening indicated by the folds in great mountain regions, some of which, like the Himalayan folds, were formed at a late date in the Earth's history, folds which in date and direction have no genetic relationship to G. H. Darwin's primitive wrinkles. Then, besides the folding and plication of the crust in some areas, we have to account for the undoubted stretching which it has suffered in other places, stretching of a kind indicated by faults so common that they are generally known as normal faults. It has been estimated by Claypole that the folding of the Appalachian Range resulted in a horizontal compression of the strata to a belt less than 65 per cent of the original breadth. According to Heim the diameter of the northern zone of the Central Alps is not more than half the original extension of the strata when they were laid down in horizontal sheets. De la Beche, in his memoir on Devon and Cornwall, which anticipated many problems of more than local interest, pointed out that, if the inclined and folded strata were flattened out again, they would cover far more ground than that to which they are now restricted on the geological map. Thus, according to Dutton, Fisher, and others, the mere contraction of the cooling globe is insufficient to account for our great rock-folds, especially great folds like those of the Alps and the Himalayas, which have been produced in quite late geological times. It is possible that this conclusion is in the main true; but in coming to this conclusion we must give due value to the number of patches which have been let into the old crustal envelope—masses of igneous rock, mineral veins, and hydrated products which have been formed in areas of temporary stretching, and have remained as permanent additions to the crust, increasing the size and bagginess of the old coat, which, since the discovery of radium, is now regarded as much older than was formerly imagined by non-geological members of the scientific world.

The peculiar nature of rock-folds presents also an obstacle no less formidable from a qualitative point of view. If the skin were merely collapsing on its shrinking core we should expect wrinkles in all directions; yet we find great folded areas like the Himalayas stretching continuously for 1,400 miles, with signs of a persistently directed overthrust from the north; or we have folded masses like the Appalachians of a similar order of magnitude stretching from Maine to Georgia, with an unmistakable compression in a north-west to south-east direction. The simple hypothesis of a collapsing crust is thus "quantitatively insufficient", according to Dutton, though this is still doubtful, and it is "qualitatively inapplicable", which is highly probable.

In addition to the facts that rock-folds are maintained over such great distances and that later folds are sometimes found to be superimposed on older ones, geologists have to account for the conditions which permit of the gradual accumulation of enormous thicknesses of strata without corresponding rise of the surface of deposition.

On the other hand, too, in folded regions there are exposures of beds superimposed on one another with a total thickness of many miles more than the height of any known mountain, and one is driven again to conclude that uplift has proceeded *pari passu* with the removal of the load through the erosive work of atmospheric agents.

It does not necessarily follow that these two processes are the direct result of loading in one case and of relief in the other; for slow subsidence gives rise

[1] Dutton, "On some of the Greater Problems of Physical Geology": Bull. Phil. Soc. Washington, vol. xi, p. 53, 1889.

to the conditions that favour deposition and the uplifting of a range results in the increased energy of eroding streams.

Thus there was a natural desire to see if Dutton's theory agreed with the variations of gravity. If the ups and downs are balanced, the apparently large mass of a mountain range ought to be compensated by lightness of material in and below it. Dutton was aware of the fact that this was approximately true regarding the great continental plateau and oceanic depressions; but he imagined that the balance was delicate enough to show up in a small hill-range of 3,000 to 5,000 feet.

The data required to test this theory accumulated during the triangulation of the United States, have been made the subject of an elaborate analysis by J. F. Hayford and W. Bowie.[1] They find that, by adopting the hypothesis of isostatic compensation, the differences between the observed and computed deflections of the vertical caused by topographical inequalities are reduced to less than one-tenth of the mean values which they would have if no isostatic compensation existed. According to the hypothesis adopted, the inequalities of gravity are assumed to die out at some uniform depth, called the depth of compensation, below the mean sea-level. The columns of crust material standing above this horizon vary in length according to the topography, being relatively long in highlands and relatively short under the ocean. The shorter columns are supposed to be composed of denser material, so that the product of the length of each column by its mean density would be the same for all places. It was found that by adopting 122 kilometres as the depth of compensation, the deflection anomalies were most effectually eliminated, but there still remained unexplained residuals or local anomalies of gravity to be accounted for.

Mr. G. K. Gilbert,[2] who was one of the earliest geologists to turn to account Dutton's theory of isostasy, has recently offered a plausible theory to account for these residual discrepancies between the observed deflections and those computed on the assumption of isostatic compensation to a depth of 122 kilometres. An attempt had already been made by Hayford and Bowie to correlate the distribution of anomalies with the main features of the geological map and with local changes in load that have occurred during comparatively recent geological times. For example, they considered the possibility of an increased load in the Lower Mississippi Valley, where there has been in recent times a steady deposition of sediment, and therefore possibly the accumulation of mass slightly in advance of isostatic adjustment. One would expect in such a case that there would be locally shown a slight excess of gravity, but, on the contrary, there is a general prevalence of negative anomalies in this region. In the Appalachian region, on the other hand, where there has been during late geological times continuous erosion, with consequent unloading, one would expect that the gravity values would be lower, as isostatic compensation would naturally lag behind the loss of overburden; this, however, is also not the case, for over a greater part of the Appalachian region the anomalies are of the positive order. Similarly, in the north central region, where there has been since Pleistocene times a removal of a heavy ice-cap, there is still a general prevalence of positive anomalies.

These anomalies must, therefore, remain unexplained by any of the obvious phenomena at the command of the geologist. G. K. Gilbert now suggests that, while it may be true that the product of the length of the unit column by its mean density may be the same, the density variations within the column

[1] J. F. Hayford, "The Figure of the Earth and Isostasy": U.S. Coast and Geodetic Survey, Washington, 1909. "Supplementary Investigation," Washington, 1910. See also *Science*, N.S., vol. xxxiii, p. 199, 1911. J. F. Hayford & W. Bowie, "The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity": U.S. Coast and Geodetic Survey Special Publication No. 10, Washington, 1912.

[2] "Interpretation of Anomalies of Gravity": U.S. Geol. Surv. Professional Paper 85-C, p. 29, 1913.

may be such as to give rise to different effects on the pendulum. If, for instance, one considers two columns of the same size and of exactly the same weight, with, in one case, the heavy material at a high level and in the other case with the heavy material at a low level, the centre of gravity of the former column, being nearer the surface, will manifest itself with a greater pull on the pendulum; these columns would be, however, in isostatic adjustment.[1]

Gilbert's hypothesis thus differs slightly from the conception put forth by Hayford and Bowie; for Gilbert assumes that there is still appreciable heterogeneity in the more deep-seated parts of the Earth, while Hayford and Bowie's hypothesis assumes that in the nuclear mass density anomalies have practically disappeared, and that there is below the depth of compensation an adjustment such as would exist in a mass composed of homogeneous concentric shells.

In order to make the Indian observations comparable to those of the United States as a test of the theory of isostasy, Major H. L. Crosthwait[2] has adopted Hayford's system of computation and has applied it to 102 latitude stations and eighteen longitude stations in India. He finds that the unexplained residuals in India are far more pronounced than they are in the United States, or, in other words, it would appear that isostatic conditions are much more nearly realized in America than in India.

The number of observations considered in India is still too small for the formation of a detailed map of anomalies, but the country can be divided into broad areas which show that the mean anomalies are comparable to those of the United States only over the Indian Peninsula, which, being a mass of rock practically undisturbed since early geological times, may be regarded safely as having approached isostatic equilibrium. To the north of the peninsula three districts form a wide band stretching west-north-westwards from Calcutta, with mean residual anomalies of a positive kind, while to the north of this band lies the Himalayan belt, in which there is always a large negative residual.

Colonel Burrard[3] has considered the Himalayan and sub-Himalayan anomalies in a special memoir, and comes to the conclusion that the gravity deficiency is altogether too great to be due to a simple geosynclinal depression filled with light alluvium such as we generally regard the Gangetic trough to be. He suggests that the rapid change in gravity values near the southern margin of the Himalayan mass can be explained only on the assumption of the existence of a deep and narrow rift in the sub-crust parallel to the general Himalayan axis of folding. A single large rift of the kind and size that Colonel Burrard postulates is a feature for which we have no exact parallel; but one must be careful not to be misled by the use of a term which, while conveying a definite mental impression to a mathematician, appears to be incongruous with our geological experience. There may be no such thing as a single large rift filled with light alluvial material, but it is possible that there may still be a series of deep-seated fissures that might afterwards become filled with mineral matter.

With this conception of a rift or a series of rifts, Colonel Burrard is led to reverse the ordinary mechanical conception of Himalayan folding. Instead now of looking upon the folds as due to an overthrust from the north, he regards

[1] It is interesting to note that the idea suggested by G. K. Gilbert in 1913 was partly anticipated by Major H L. Crosthwait in 1912 (Survey of India, Professional Paper No. 13, p. 5). Major Crosthwait, in discussing the similar gravity anomalies in India, remarks parenthetically: "Assuming the doctrine of isostasy to hold, is it not possible that in any two columns of matter extending from the surface down to the depth of compensation there may be the same mass, and yet that the density may be very differently distributed in the two columns? These two columns, though in isostatic equilibrium, would act differently on the plumb-line owing to the unequal distribution of mass. The drawback to treating this subject by hard and fast mathematical formulæ is that we are introducing into a discussion of the constitution of the earth's crust a uniform method when, in reality, probably no uniformity exists."

[2] Survey of India, Professional Paper No. 13, 1912.

[3] Ibid., No. 12, 1912.

the corrugations to be the result of an under-creep of the sub-crust towards the north. Thus, according to this view, the Himalaya, instead of being pushed over like a gigantic rock-wave breaking on to the Indian *Horst*, is in reality being dragged away from the old peninsula, the depression between being filled up gradually by the Gangetic alluvium. So far as the purely stratigraphical features are concerned, the effect would be approximately the same whether there is a superficial overthrust of the covering strata or whether there is a deep-seated withdrawal of the basement which is well below the level of observation.

Since the Tibetan expedition of ten years ago we have been in possession of definite facts which show that to the north of the central crystalline axis of the Himalaya there lies a great basin of marine sediments forming a fairly complete record from Palæozoic to Tertiary times, representing the sediments which were laid down in the great central Eurasian ocean to which Suess gave the name *Tethys*. We have thus so far been regarding the central crystalline axis of the Himalaya as approximately coincident with the old northern coastline of Gondwanaland; but, if Colonel Burrard's ideas be correct, the coastline must have been very much further to the south before the Himalayan folding began.

Representing what the Geological Survey of India regards as the orthodox view, Mr. H. H. Hayden[1] has drawn attention to some conclusions which, from our present geological knowledge, appear to be strange and improbable in Colonel Burrard's conclusions, and he also offers alternative explanations for the admitted geodetic facts. Mr. Hayden suggests, for instance, that the depth of isostatic compensation may be quite different under the Himalayan belt from that under the regions to the south. His assumptions, however, in this respect are, as pointed out by Colonel G. P. Lenox Conyngham,[2] at variance with the whole theory of isostasy. Mr. Hayden then suggests that most of the excessive anomalies would disappear if we took into account the low specific gravity of the sub-Himalayan sands and gravels of Upper Tertiary age as well as of the Pleistocene and recent accumulations of similar material filling the Indo-Gangetic depression. It would not be at all inconsistent with our ideas derived from geology to regard the Gangetic trough as some 3 or 4 miles deep near its northern margin, thinning out gradually towards the undisturbed mass of the Indian Peninsula, and Mr. R. D. Oldham,[3] with this view, has also calculated the effect of such a wedge of alluvial material of low specific gravity, coming to the conclusion that the rapid change in deflection, on passing from the Lower Himalaya southward towards the peninsula, can mainly be explained by the deficiency of mass in the alluvium itself.

It is obvious that, before seeking for any unusual cause for the gravity anomalies, we ought to take into account the effect of this large body of alluvium which lies along the southern foot of the range. It is, however, by no means certain that a thick mass of alluvial material, accumulated slowly and saturated with water largely charged with carbonate of lime, would have a specific gravity so appreciably lower than that of the rocks now exposed in the main mass of the Himalaya as to account for the residual anomalies. Some of the apparent deficiency in gravity is due to this body of alluvium, but it will only be after critical examination of the data and more precise computation that we shall be in a position to say if there is still room to entertain Colonel Burrard's very interesting hypothesis.

By bringing together the geological and geodetic results we notice five roughly parallel bands stretching across Northern India. There is (1) a band of abnormal high gravity lying about 150 miles from the foot of the mountains, detected by the plumb-line and pendulum; (2) the great depression filled by the Gangetic alluvium; (3) the continuous band of Tertiary rock, forming the sub-Himalaya, and separated by a great boundary overthrust from (4) the main

[1] Rec. Geol. Surv. Ind., vol. xliii, pt. ii, p. 138, 1913.
[2] Rec. Surv. Ind., vol. v, p. 1.
[3] Proc. Roy. Soc., ser. A, vol. xc, p. 32, 1914.

mass of the Outer and Central Himalaya of old unfossiliferous rock, with the snow-covered crystalline peaks flanked on the north by (5) the Tibetan basin of highly fossiliferous rocks formed in the great Eurasian mediterranean ocean that persisted up to nearly the end of Mesozoic times.

That these leading features in North India can hardly be without genetic relationship one to another is indicated by the geological history of the area. Till nearly the end of the Mesozoic era the line of crystalline, snow-covered peaks now forming the Central Himalaya was not far from the shore-line between Gondwanaland, stretching away to the south, and Tethys, the great Eurasian ocean. Near the end of Mesozoic times there commenced the great outwelling of the Deccan Trap, the remains of which, after geological ages of erosion, still cover an area of 200,000 square miles, with a thickness in places of nearly 5,000 feet. Immediately after the outflow of this body of basic lava, greater in mass than any known eruption of the kind, the ocean flowed into North-West India and projected an arm eastwards to a little beyond the point at which the Ganges now emerges from the hills. Then followed the folding movements that culminated in the present Himalayan Range, the elevation developing first on the Bengal side, and extending rapidly to the north-west until the folds extended in a great arc for some 1,400 miles from south-east to north-west.

New streams developed on the southern face of the now rising mass, and although the arm of the sea that existed in early Tertiary times became choked with silt, the process of subsidence continued, and the gradually subsiding depression at the foot of the hills as fast as it developed became filled with silt, sand, gravel, and boulders in increasing quantities as the hills became mountains and the range finally reached its present dimensions, surpassing in size all other features of the kind on the face of the globe.

Now, it is important to remember that for ages before the great outburst of Deccan Trap occurred there was a continual unloading of Gondwanaland, and a continual consequent overloading of the ocean bed immediately to the north; that this process went on with a gradual rise on one side and a gradual depression on the other; and that somewhere near and parallel to the boundary line the crust must have been undergoing stresses which resulted in strain, and, as I suggest, the development of those fissures that let loose the floods of Deccan Trap and brought to an end the delicate isostatic balance.

During the secular subsidence of the northern shore-line of Gondwanaland, accompanied by the slow accumulation of sediment near the shore and the gradual filing away of the land above sea-level, there must have been a gradual creep of the crust in a northerly direction. Near the west end of the Himalayan arc this movement would be towards the north-west for a part of the time; at the east end the creep would be towards the north-north-east and north-east. Thus there would be a tendency from well back in Palæozoic times up to the end of the Cretaceous period for normal faults—faults of tension—to develop on the land, with a trend varying from W.S.W.–E.N.E. to W.N.W.–E.S.E. across the northern part of Gondwanaland. We know nothing of the evidence now pigeon-holed below the great mantle of Gangetic alluvium, while the records of the Himalayan region have been masked or destroyed by later foldings. But in the stratified rocks lying just south of the southern margin of the great alluvial belt we find a common tendency for faults to strike in this way across the present peninsula of India. These faults have, for instance, marked out the great belt of coal-fields stretching for some 200 miles from east to west in the Damuda Valley. On this, the east side of India, the fractures of tension have a general trend of W.N.W.–E.S.E. We know that these faults are later than the Permian period, but some of them certainly were not much later.

If we now go westwards across the Central Provinces and Central India and into the eastern part of the Bombay Presidency, we find records of this kind still more strikingly preserved; for where the Gondwana rocks, ranging from Permo-Carboniferous to Liassic in age, rest on the much older Vindhyan Series, we find three main series of these faults. One series was developed before Permo-Carboniferous times; another traverses the Lower Gondwanas, which range up to about the end of Permian times; while the third set affects the younger and Upper Gondwanas of about Rhætic or Liassic age. Although the present topography of the country follows closely the outlines of the geological formations, it is clear from the work of the Geological Survey of India that these outlines were determined in Mesozoic times, and that the movements which formed the latest series of faults were but continuations of those which manifested themselves in Palæozoic times. According to Mr. J. G. Medlicott, the field data showed "that a tendency to yield in general east and west or more clearly north-east and south-west lines existed in this great area from the remote period of the Vindhyan fault".[1] The author of the memoir and map on this area was certainly not suspicious of the ideas of which I am now unburdening my mind; on the contrary, he attempted and, with apologies, failed to reconcile his facts to views then being pushed by the weight of 'authority' in Europe. This was not the last time that facts established in India were found (to use a field geologist's term) unconformably to lie on a basement of geological orthodoxy as determined by authority in Europe. It is important to notice that the series of faults referred to in the central parts of India are not mere local dislocations, but have a general trend for more than 250 miles.

A fault must be younger, naturally, than the strata which it traverses, but how much younger can seldom be determined. Intrusive rocks of known age are thus often more useful in indicating the age of the fissures through which they have been injected, and consequently the dykes which were formed at the time of the eruption of the great Deccan Trap give another clue to the direction of stresses at this critical time, that is, towards the end of the Cretaceous period, when the northerly creep had reached its maximum, just before Gondwanaland was broken up. If, now, we turn to the geological maps of the northern part of Central India, the Central Provinces, and Bengal, we find that the old Vindhyan rocks of the Narbada Valley were injected with hundreds of trap-dykes which show a general W.S.W.-E.N.E. trend, and thus parallel to the normal tension faults, which we know were formed during the periods preceding the outburst of the Deccan Trap. This general trend of faults and basic dykes is indicated on many of the published geological maps of India covering the northern part of the peninsula, including Ball's maps of the Ramgarh and Bokaro Coal-fields[2] and of the Hutar Coal-field,[3] Hughes' Rewa Gondwana basin,[4] Jones' southern coal-fields of the Satpura basin,[5] and Oldham's general map of the Son Valley.[6]

We see, then, that the development of fissures with a general east-west trend in the northern part of Gondwanaland culminated at the end of the Cretaceous period, when they extended down, probably, to the basic magma lying below the crust either in a molten state or in a state that would result in fluxion on the relief of pressure. That the molten material came to the surface in a superheated and liquid condition is shown by the way in which it has spread out in horizontal sheets over such enormous areas. Throughout this great expanse of lava there are no certain signs of volcanic centres, no conical slopes around volcanic necks; and one might travel for more than 400 miles from Poona to Nagpur over sheets of lava which are still practically horizontal. There is nothing exactly like this to be seen elsewhere to-day. The nearest approach to it is among the Hawaiian calderas, where the highly mobile basic lavas also show the characters of superfusion, glowing, according to J. D. Dana,[7] with a white heat, that is, at a temperature not less than about 1,300° C.

Mellard Reade has pointed out that the Earth's crust is under conditions of stress analogous to those of a bent beam, with, at a certain depth, a "level of

[1] Mem. Geol. Surv. Ind., vol. ii, pt. ii, p. 256, 1860.
[2] Ibid., vol. vi, pt. ii.
[3] Ibid., vol. xv.
[4] Ibid., vol. xxi, pt. iii.
[5] Ibid., vol. xxiv.
[6] Ibid., vol. xxxi, pt. i.
[7] *Characteristics of Volcanoes*, 1891, p. 200.

no strain". Above this level there should be a shell of compression, and under it a thicker shell of tension. The idea has been treated mathematically by C. Davison, G. H. Darwin, O. Fisher, and M. P. Rudski, and need not be discussed at present. Professor R. A. Daly has taken advantage of this view concerning the distribution of stresses in the crust to explain the facility for the injection of dykes and batholiths from the liquid, or potentially liquid, gabbroid magma below into the shell of tension.[1] He also shows that the injection of large bodies of basic material into the shell of tension tends on purely mechanical grounds to the formation of a depression or geosyncline. If this be so, are we justified in assuming that the heavy band following the southern margin of the Gangetic geosyncline is a 'range' of such batholiths? The idea is not entirely new; for O. Fisher made the suggestion more than twenty years ago that the abnormal gravity at Kalianpur was due to "some peculiar influence (perhaps of a volcanic neck of basalt)".[2]

Daly's suggestion, however, taken into account with the history of Gondwanaland, may explain the peculiar alignment of the heavy subterranean band, parallel to the Gangetic depression and parallel to the general trend of the peninsular tension-faults and fissures that followed the unloading of Gondwanaland and the heavy loading of the adjoining ocean bed along a band roughly parallel to the present Himalayan folds.

R. S. Woodward objected that isostasy does not seem to meet the requirements of geological continuity, for it tends rapidly towards stable equilibrium, and the crust ought therefore to reach a stage of repose early in geologic time.[3] If the process of denudation and rise, with adjoining deposition and subsidence, occurred on a solid globe, this objection might hold good. But it seems to me that the break-up of Gondwanaland and the tectonic revolutions that followed show how isostasy can defeat itself in the presence of a sub-crustal magma actually molten or ready to liquefy on local relief of pressure. It is possible that the protracted filing off of Gondwanaland brought nearer the surface what was once the local level of no strain and its accompanying shell of tension.

The conditions existing in Northern Gondwanaland before late Mesozoic times must have been similar to those in South-West Scotland before the occurrence of the Tertiary eruptions, for the crust in this region was also torn by stresses in the S.W.–N.E. direction with the formation of a remarkable series of N.W.–S.E. dykes which give the 1 in. geological maps in this region a regularly striped appearance.

There is no section of the Earth's surface which one can point to as being now subjected to exactly the same kind and magnitude of treatment as that to which Gondwanaland was exposed for long ages before the outburst of the Deccan Trap; but possibly the erosion of the Brazilian highlands and the deposition of the silt carried down by the Amazon, with its southern tributaries, and by the more eastern Araguay and Tocantins, may result in similar stresses which, if continued, will develop strains, and open the way for the subjacent magma to approach the surface or even to become extravasated, adding another to the small family of so-called fissure-eruptions.

The value of a generalization can be tested best by its reliability as a basis for prediction. Nothing shows up the shortcomings of our knowledge about the state of affairs below the superficial crust so effectually as our inability to make any useful predictions about earthquakes or volcanic eruptions. For many years to come in this department of science the only worker who will ever establish a claim to be called a prophet will be one in Cicero's sense—"he who guesses well."

[1] R. A. Daly, "Abyssal Igneous Injection as a Causal Condition and as an Effect of Mountain-building": Amer. Journ. Sci., vol. xxii, p. 205, September, 1906.

[2] *Physics of the Earth's Crust*, 2nd ed., 1889, p. 216.

[3] Address to the Section of Mathematics and Astronomy of the Amer. Assoc., 1889. Smithsonian Report, 1890, p. 196.

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

(1) THE PERMO-CARBONIFEROUS BRECCIA, A DESERT FORMATION.
By H. T. FERRAR, M.A., F.G.S.[1]

DURING the meeting of the Association at Birmingham last year members of this Section had an ample opportunity for visiting the chief exposures of the so-called Permian breccia of the midland counties of England. This deposit may be briefly described as a mass of sandstones and marls with occasional sheets of angular breccia, the latter consisting in a large measure of volcanic rocks, grits, slates, and limestones which can be identified with rocks on the borders of Wales. The organic remains which have been recorded are few, but such as occur are indicative chiefly of terrestrial surfaces.

The origin of the breccia has given rise to many speculations, amongst which may be mentioned—

1. Murchison (1839) regarded it as a volcanic or trappoid breccia marking the position of underground masses of volcanic rocks hidden under a cover of their own fragments.

2. Ramsay (1855) ascribed its origin to the existence of glacial conditions in Permian times.

3. Geikie (1892) says with regard to Scotland that the breccia has evidently accumulated in small lakes or narrow fiords during periods of great and rapid denudation following uplift of the Upper Carboniferous rocks.

4. Bonney (1902) concludes that breccias are usually indicative of continental conditions, but that glaciers are necessary for the transport of the larger boulders.

5. Lapworth (1912) holds that they are the memorials of local Alpine conditions.

In Egypt a chain of fold-mountains forms the watershed between the Nile and the Red Sea, and the mountains are intersected and drained by steep-sided gorges or wadis. The climate is arid with occasional heavy thunderstorms causing temporary torrents, which sweep forward all rock-material loosened during the prevailing dry climate. The wadi beds receive continuously a fresh supply of angular debris shed from the adjacent bare hillsides, and any fragments which may have become rounded or subangular are often shattered before the next flood sweeps them forward another stage on their journey towards a more permanent resting-place, namely, the alluvial plain at the wadi-mouth. Blocks slipping down the bare hillsides become scratched or they may be scratched by mutual impact during a sudden rush of flood-water. Great blocks are often carried fifty or one hundred miles down the wadi channels, and the agency of ice need not be invoked to explain their transport.

The valley fill of most wadis in the Eastern Desert of Egypt is an unconsolidated breccia so similar to the breccia exposed on Ley Hill, near Birmingham, that there is little room for doubt that the two originated under similar climatic conditions.

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

(2) CLIMATES AND PHYSICAL CONDITIONS OF THE EARLY PRE-CAMBRIAN. By Professor A. P. COLEMAN, F.R.S., Toronto.

OUR knowledge of the later Pre-Cambrian permits us to speak of desert conditions in the Keweenawan or Torridonian and of an ice age followed by a cool climate in the Huronian, but little evidence has been given as to earlier climates. Recent work in Canada shows that the Sudbury Series, of Pre-Laurentian age and very much older than the Huronian, includes all types of sediments, often well enough preserved to show cross-bedding, ripple-marks, and annual layers indicating the change of seasons. They must have been formed near the margin of a continent where granites weathered under a cool and moist climate. They seem to be delta materials deposited by great rivers.

The highly metamorphosed sediments of the still older Grenville and Keewatin Series (Lewisian?) have lost their original structures, but the gneisses, quartzites, and marbles must have been clay, sand, and limestone in the beginning, and the graphite may have originated in plants. Land surfaces must have been attacked by water and air to produce these materials, and there is no evidence that the climate was hot. These are the earliest known formations, so that air and water worked in the usual way at the beginning of recorded geological time.

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(3) THE TERTIARY BROWN COAL-BEDS OF VICTORIA. By H. HERMAN, B.C.E., M.M.E., F.G.S., Director of the Geological Survey of Victoria.

THE brown coal-beds of Victoria are probably the thickest yet recorded in the world. The more extensive areas are the La Trobe Valley, Alberton, Altona, and Lal Lal. Minor beds are widely distributed.

The geological age has not yet been definitely fixed, except at Altona, where a brown coal-seam 140 feet thick underlies marine Oligocene beds. Flows of basalt overlie the brown coal in places, and underlie it in others. The range in age is probably from Oligocene upwards. Seams outcrop at Narracan, Thorpdale, Dean's March, Morwell, and Boolarra.

Where below the surface, the seams are prospected by boring. In many bores coal of several hundred feet in thickness is shown; one bore had an aggregate thickness of 781 feet of coal in a depth of 1,010 feet. The overburden is from a few feet to 500 feet deep.

In the Alberton area of about 300 square miles and the La Trobe Valley area of 700 square miles there is probably 30,000,000,000 tons of coal. The approximate area at Altona is 200 square miles, with a probable average thickness of 50 feet of coal. At Lal Lal the coal covers 3 square miles with an average thickness of 80 feet.

The geological and geographical distribution of the various brown coal-seams is still being ascertained by boring; the bores are being systematically tested for calorific value, gas production, and by-products. A typical analysis of the brown coal, as freshly mined, is—

https://doi.org/10.1017/S0016756800153191 Published online by Cambridge University Press

	Per cent.
H_2O	53·00
V.H.C.	24·50
F.C.	21·50
Ash	1·00
	100·00

Sulphur	0·7 per cent.
Nitrogen	0·3 per cent.
Calorific value	5500–6000 B.T.U.
Evaporation value	4 lb. water.
Gas per ton	6,500 cubic feet.
Ammonium sulphate per ton (theoretical),	32 lb.

Experimental work has also proved that under proper conditions a firm hard briquette can be produced without the aid of an agglutinant binder. It is suitable also for use in the gas producer, the improvements in which of recent years bid fair to give brown coal an important place in the power-fuels of the world at no distant date.

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(4) The Sedimentary Rocks of South Victoria Land. By F. Debenham, B.A., B.Sc., Geologist to Captain Scott's Last Expedition, 1910–13.

THE topography of the area was first described in brief, showing how the comparatively meagre knowledge of the geology of such a vast region is due largely to its plateau structure, which presents merely an edge of the continent, the interior being completely covered by a thick ice-cap. The systems at present known to occur were then described in order of their age.

1. The Foundation Rocks, a vast complex of gneisses, schists, and crystalline limestones, largely of sedimentary origin, with their axes of folding in a meridional direction. They must at present be referred to Pre-Cambrian age, though a less altered series of slates and quartzites in the Cape Adare region may possibly be younger.

2. The Cambrian of the Beardmore Glacier. The outcrop of this series has not yet been visited, the evidence for its occurrence being derived from moraine blocks. Its probable disposition was sketched, and a possible connexion between the Archæocyathinæ found in these blocks and those found in the Weddell Sea was traced.

3. The Upper Devonian shales of Granite Harbour. This thin bed of shales was formerly supposed to be a part of the Beacon Sandstone Series, with which it is quite conformable, but evidence was brought forward to prove that it is of earlier date, the most important being the occurrence of numerous Devonian fish scales.

4. The Permo-Carboniferous Sandstones. The already well-known Beacon Sandstone was proved to be of this age from the fossils brought back by the last expedition. The series was thoroughly described from three type areas, and its probable limits indicated. An attempt to correlate it with other large Permo-Carboniferous regions in the world was made, having special regard to the Australian examples. The great variations in lithological character in different parts of the series was described, and reasons for them suggested from the stratigraphical relationships, with a sketch of the probable climatic

conditions at the time of deposition drawn chiefly from the internal evidence of the sandstones. The coal-beds associated with the series were described in detail.

5. Recent. A brief description of the only other sedimentary deposits yet found was given, they consisting chiefly of local beds of volcanic tuffs and some moraine deposits.

The paper concluded with a brief sketch of the history of South Victoria Land as compared with that of the South American Quadrant as recorded by their respective sedimentary deposits.

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(5) VICTORIA GRAPTOLITES. By T. S. HALL, M.A., D.Sc., Lecturer in Biology in the University of Melbourne.

THE Silurian and Ordovician graptolite-bearing rocks of Victoria occupy about 20,000 square miles, and over a hundred species have been recorded.

Very little is known of the Silurian. The Ordovician is divided into Upper and Lower, but probably represents a continuous series. The Upper is characterized by the presence of Dicranograptidæ. No zonal work has been done in the field, though collections yielding about fifty recorded species have been made.

Four divisions are recognized in the Lower Ordovician, namely, Darriwillian, Castlemainian, Bendigonian, and Lancefieldian, at the base. There are several subdivisions of these formations. The characters were briefly indicated in the GEOLOGICAL MAGAZINE by the author in 1899. Subsequent work by T. S. Hart, F.G.S., at Daylesford, has confirmed the sequence established. Large collections made by the Survey at many localities have somewhat extended our knowledge of the fauna and its distribution, but without adding any features of great importance.

The Upper Ordovician ranges north from Eastern Victoria for 300 miles into New South Wales. In New Zealand Lancefieldian occurs at Preservation Inlet, and two Castlemaine zones occur as well. It is probable that the Victorian sequence, and not the British, as stated, will be found.

Broadly, the sequence of Australian Graptolites agrees with the European, but in details is closer to that of New York, as Ruedemann has pointed out. The important differences in the range of *Didymograptus bifidus*, *D. caduceus*, *D. nicholsoni*, *Loganograptus*, *Clonograptus rigidus*, and some other genera and species negative the idea that graptolite zones are world-wide, and as no one believes that all genera and species originated in one locality and radiated thence this is what we should expect.

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(6) ON THE TERM PERMO-CARBONIFEROUS AND ON THE CORRELATION OF THAT SYSTEM. By W. S. DUN and T. W. EDGEWORTH DAVID.

THE term Permo-Carboniferous was originally applied to certain formations in Queensland which on stratigraphical evidence were at the time considered to belong to one and the same general system. At the time it was considered that a series of strata at

https://doi.org/10.1017/S0016756800153191 Published online by Cambridge University Press

Gympie, which contained an assemblage of fossils of distinct Permian affinities, were stratigraphically below another set of strata known as the Star Beds. The latter contain among other fossils *Phillipsia*, *Lepidodendron Australe*, and *Aneimites*, all typical Carboniferous fossils in Australia, and the first mostly of Devonian age. Accordingly these formations were grouped together under the term Permo-Carboniferous, and the name has subsequently been widely used. It has now been proved that, so far as Queensland is concerned, the name has been given in error. The Gympie Beds are stratigraphically above the Star Beds, not below as was originally supposed. Nowhere in Australia or Tasmania has a single trilobite or *Lepidodendron* ever been found in our Carboniferous rocks proper. In the absence of a zoning of these Carboniferous rocks it is impossible to say what exactly are its equivalents in other parts of the world. If it is wholly Lower Carboniferous, as some suppose, there may be some justification for the retention of the term Permo-Carboniferous, but if its fauna and flora ascend to Upper Carboniferous, then it is suggested that there is much to be said in favour of using the term Permian instead. In Russia *Schizodus* occurs in numbers beneath the whole, not only of the *Glossopteris* beds, but of the *Gangamopteris* beds also of the Dwina system. In South America the Lower Rocks of the Santa Catharina system appear to be more Permian than anything else, and the occurrence of the strong swimming reptile *Mesosaurus* both in the Permo-Carboniferous rocks of South America and of South Africa suggests that the South African Permo-Carboniferous rocks also may be chiefly Permian.

In the correlation of the Australian Permo-Carboniferous formations, special emphasis is laid on the Indian facies of the West Australian Permo-Carboniferous fauna.

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(7) The Evolution of Victoria during the Kainozoic Period.

By D. J. Mahony, M.Sc., F.G.S., Geological Survey of Victoria.

THE Kainozoic period in Victoria is characterized by great earth movements accompanied by volcanic action; the present topography is a consequent development.

The central highland area (Palæozoic rocks) extends from the eastern boundary of the state westwards to the Grampians; to the north and south it is bounded by low-lying plains (Kainozoic strata), which gradually broaden towards the west until they merge into one another. To the south Wilson's Promontory (granite), South Gippsland (Mesozoic), and the Cape Otway district (Mesozoic) rise above the plains. The highland area is essentially a dissected peneplain sinking from some 5.000 feet above sea-level in Gippsland to 900 feet at its western extremity; the only Kainozoic rocks upon it are river-gravels, lake-deposits, and volcanics.

The plains (500 feet) are areas of Kainozoic sedimentation with some interbedded and overlying volcanic rocks; the sedimentary series consists of lacustrine or estuarine beds, followed by marine clays (Oligocene), foraminiferal limestones (Miocene), and sandstones (Pliocene). These beds rest upon Palæozoic or Mesozoic rocks.

On the surface of the ancient peneplain, 5,000 feet above sea-level, (?) Miocene plant-remains and river-gravels are preserved beneath basalt at Dargo High Plains. This indicates a long pre-Miocene period of quiescence followed by a great uplift. This area has not been submerged during the Kainozoic.

The nature of the Kainozoic Series indicates that, outside the highland area, a gradual subsidence of considerable magnitude (Oligocene and Miocene), accompanied by volcanic outbreaks (Miocene), was followed by re-elevation to a maximum of about 900 feet above sea-level (Pliocene or post-Pliocene). There is evidence to show that the movements were not uniform in direction, though the net result was depression or elevation. Bass Strait is a recently sunken area in which equilibrium has not yet been established.

The nearly horizontal position of the Kainozoic rocks indicates that the movements were vertical; and there are, moreover, examples of Kainozoic faults in which the differential movement amounts to 900 feet.

The volcanic rocks are basaltic except for sporadic occurrences of alkali rocks in Eastern, Central, and Western Victoria.

The Older Basalts are most abundant to the east of Melbourne. Some remnants occur on the ancient peneplain 3,000 feet above the present streams, but the most extensive areas are at lower levels in South Gippsland. At Flinders the Older Basalt underlies marine Miocene, and has been proved by boring to be over 1,300 feet thick, and to extend from sea-level to that depth. In some instances the age can be conclusively proved, but in others the evidence is poor. These basalts are associated with the first great period of earth movements.

The Newer Basalts are most extensively developed in the western district, where their northern boundary is not far from the 500 ft. contour; here they overlie marine Kainozoics. Large areas are also found on the plateau west of Kilmore and along its northern flanks. The Newer Basalts are never covered by marine deposits, except recent accumulations near the coast, their surface is little denuded, and many of the cones of loose scoria are almost perfect. It appears that the Newer Basalts mark the close of the last great movement which elevated the marine Kainozoics.

In New South Wales and South Australia earth movements on a grand scale took place during the Kainozoic period, yet volcanic action was comparatively insignificant.

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(8) ON THE TERTIARY ALKALI ROCKS OF VICTORIA. By ERNEST W. SKEATS, D.Sc., A.R.C.S., F.G.S., Professor of Geology and Mineralogy, University of Melbourne.

FROM Mount Leinster in Benambra, Frenchman's Hill near Omeo, and Noyang in Dargo, three areas in Eastern Victoria, the late Dr. Howitt (1) described igneous rocks which belong to the alkali series. They were all regarded by Howitt as of Palæozoic age. The age of the rocks of Noyang, which consist mainly of intrusions and lava-flows of quartz-ceratophyre, has not been closely investigated

https://doi.org/10.1017/S0016756800153191 Published online by Cambridge University Press

and may be Palæozoic. Recent work (2), however, has shown, especially in the case of the Omeo rocks, that they are probably of mid- or even of late Tertiary age. The alkali rocks of Frenchman's Hill, described by Howitt as intrusive orthophyres, consist really in the main of lava-flows of anorthoclase trachyte which has a very scoriaceous margin to the flows. There is a central plug of a coarser quartz-bearing rock allied to solvsbergite and a more or less radial system of dykes which are principally trachytic in character. Some, however, contain quartz, one at least is a bostonite, and six or seven prove to be dykes of nepheline phonolite. The district is one which has been affected by a succession of elevatory movements of the plateau type since the mid-Tertiary period, and, according to Griffith Taylor (3), a more or less meridional Senkungsfeld runs through the Omeo District a few miles east of Frenchman's Hill. The rocks of Mount Leinster in Benambra consist principally of solvsbergites, bostonites, and pyroclastic rocks of alkali trachyte. Petrologically and chemically many of the rocks of Mount Leinster and of Frenchman's Hill closely resemble some of the alkali rocks of Mount Macedon, and, like them, are probably of mid-Tertiary age. The district has been elevated at intervals during the Tertiary period, but physiographically has not been closely studied.

About 14 miles north-east from Mansfield in North-Central Victoria and about 3 miles from Tolmie, in the Tolmie Highlands, there occurs a volcanic hill, known locally as Gallows Hill, which has recently been shown to consist of a volcanic centre of probably late Tertiary age and to consist of lava-flows of nepheline phonolite. From a locality near Barwite, east of Mansfield, another nepheline phonolite has been found, but its field relations are at present uncertain and no account of either of these rocks has yet been published. Fenner (4) has recently shown that block elevation and depression have affected the Mansfield area in recent geological times, and that Gallows Hill lies near one of the fault scarps.

The best-known area of alkali rocks in Victoria is the Mount Macedon District, about 40 miles north-west of Melbourne (5). The series is of mid Tertiary to late Tertiary age, and the rock sequence from below upwards, while not always demonstrable, appears to be as follows: anorthoclase trachyte, solvsbergite, anorthoclase basalt, macedonite, woodendite, anorthoclase-olivine trachyte, olivine-anorthoclase trachyte, limburgite. Immediately succeeding these alkali rocks come lava-flows of normal basalt and of andesitic basalt. The new types macedonite and woodendite contain over 1 per cent of P_2O_5, and are related to the orthoclase basalts and to the mugearites.

While this part of Victoria shows evidence, by the existence of more than one elevated peneplain, of successive movements of the plateau type, no definite evidence of faulting or differential movement has been recognized in the district. In the western district of Victoria more or less extensive lava-flows of anorthoclase trachyte occur near Coleraine, Carapook, etc. (6). Generally the trachytes appear to be older than the newer basalts, but near Coleraine a dyke of trachyte penetrates a small hill composed of a basic rock resembling olivine basalt, while at the Hummocks north of Casterton another trachyte dyke similarly penetrates a vent or small flow of olivine basalt. Among the ejected blocks from the earlier members of the Pleistocene newer basalts of Lake Bullenmerri, near Camperdown, are some consisting of essexite and containing analcite. In the western district of Victoria clear evidence of comparatively recent elevatory movements is noticeable. No definite faults have yet been proved, however, and the normal basalts are much more widely spread than the alkali rocks. In view of Harker's generalization as to the close correspondence between the occurrence of alkali rocks and elevatory movements of the plateau type, generally accompanied by faulting, the above reference to earth movements is pertinent. Practically no folding movements are known among the Tertiary rocks of Victoria, while plateau movements, generally of elevation, sometimes of depression and accompanied by faulting, are widespread. Near Omeo and Mansfield, where faulting has been demonstrated or inferred, the highly alkaline types of nepheline phonolite are developed, but the widespread plateau movements in Victoria are more specially associated with the occurrence of the normal basalts. The alkali trachytes and allied rocks are intercalated between an older and a newer basalt series, are developed only sporadically at certain centres, and, as at Macedon, are closely associated in the field with the newer basalts as rocks of slightly greater antiquity but belonging to the same volcanic period.

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(9) ON THE ORIGIN AND RELATIONSHIP OF THE VICTORIAN KAINOZOIC ALKALI ROCKS. By H. S. SUMMERS, D.Sc.

ALKALI rocks of Kainozoic age occur in Victoria in the Macedon District, near Coleraine and Carapook in the Western District, and in the neighbourhood of Omeo and Mansfield in North-Eastern Victoria. Ejected blocks from the volcanoes near Camperdown have been described as essexite, and a similar type, also probably ejected, has been found near Kyneton. With the exception of the occurrences of Omeo and Mansfield all these alkali rocks are closely associated with the Upper Kainozoic calcic basalts, and the field relations are such that there is little doubt that the alkali rocks and the basalts are genetically related.

Numerous analyses (mainly unpublished) have been made of Victorian basalts, and these show that they are fairly normal in composition, and consequently should belong to Harker's Calcic or Pacific Branch of Igneous rocks, whereas the solvsbergites, trachytes, etc., of Macedon, the phonolites of Omeo and Mansfield, the essexites (?) of Camperdown and Kyneton, and the trachytes and anorthoclase basalts of the Coleraine area must be placed in the Alkali or Atlantic Branch. It follows, then, that the evidence of the Victorian Kainozoic rocks does not support Harker's generalization on Petrographic Regions.

A number of first-class analyses have been made of the principal types of the Macedon Series, and variation diagrams based on these analyses have been drawn (see Bulletin of the Geological Survey of Victoria, No. 24, 1912, and Proceedings of the Royal Society of Victoria, N.S., vol. xxvi, pt. ii, 1914). It was found that by re-calculating the analyses to 100 per cent with the water omitted and the ferric oxide reduced to ferrous, the curves obtained were better than those plotted from the original analyses. Certain of the analyses did not conform to the curves, and at first these were regarded as representing hybrid types, but additional work showed that they represented complementary types and resulted from the splitting up of a magma instead of the mixing of magmas. A few analyses have been made of the alkali rocks from other Victorian areas, but a sufficient number have not been made to show the relationship of the various types to one another.

The conclusions are that the Kainozoic alkali rocks of Victoria are derived from the calcic basalts by differentiation, giving rise to several lesser magma reservoirs. In the case of the Macedon magma further differentiation took place, and a series of lavas were extruded which in general showed a serial relationship to one another, but a certain number were complementary to one another.

REVIEWS.

I.—Igneous Rocks and their Origin. By R. A. Daly, Sturgis-Hooper Professor of Geology, Harvard University. New York and London, 1914.

EVERY field-student of igneous intrusions must at some period of his career have been confronted by the following problem: before the intrusion occurred, what occupied the space now filled with igneous rock, and what has become of that material? Up to the present time this problem has scarcely been considered by British petrographers, at any rate in print, whatever may have been their private speculations on the subject. This is the most important question that the author of this book sets out to answer; if, after reading it, we are not perhaps prepared to accept all his conclusions in full in exactly the sense intended by the author, it is at any rate clear that he has provided abundant food for thought among petrologists.

Professor Daly has long been known as an advocate of *stoping* as an important mechanism in rock-intrusion. Now, stoping is merely another name for assimilation, since it implies the fusion and