II.—The recent Discussion on the Origin of the Himalayas.

By R. D. Oldham, F.R.S., V.P.G.S., etc.

THE discussion on the origin of the Himalayas, started by Sir T. H. Holland's review [1] of Colonel Burrard's memoir, appears to have been led, by the concluding sentence of that review, into an unprofitable channel; for alike in the review and in the succeeding articles by Mr. Fisher [2] and Colonel Burrard [3] it seems to have been accepted that only two theories are applicable, firstly, Mr. Fisher's discussion of the theory of the disturbed tract contained in chapter x of the first and chapter xiii of the second edition of his *Physics of the Earth's Crust*, and, secondly, that developed by Colonel Burrard. Further, it is assumed that the former is dependent on the hypothesis of a fluid earth and the latter such as should follow from the hypothesis of a solid, highly heated, and cooling globe; the connexion, in either case, being so close that the acceptance of one or other hypothesis, of the constitution of the earth, necessitates the acceptance of one and the rejection of the other of the theories of the origin of the Himalayas. This, however, is not the case; Mr. Fisher's treatment of the disturbed tract, though originally a development of his theory of a fluid earth, and quite consistent with it, is equally consistent with the hypothesis of a solid earth, for it is hardly conceivable that the substance of the most solid of globes would not yield and flow under stresses of the magnitude and duration of those involved by the support of a mountain range such as the Himalayas, and, once such a flow commenced, there would be developed a system of quasi-hydrostatic support, and an isostasy caused by a species of flotation, which is all that is demanded by the general theory or by the adaptation to the particular case of the Himalayas contained in chapter xviii of the second edition of the *Manual of the Geology of India.* I, at least, have never regarded this as having any but a very remote bearing on the hypothesis of a solid or fluid condition of the interior of the earth.

On the other hand, Colonel Burrard's explanation, so far from being in accord with the hypothesis of a solid, cooling, earth, is in reality inconsistent with it, and his view, that, in such a globe, rifts would open by contraction from the surface downwards, is the reverse of what would actually take place. The conditions existing in a partially cooled solid globe are well understood; I believe they were first pointed out by Mr. Mellard Reade in 1876, but once indicated they became a truism, and may be very briefly explained. In such a globe there would be, on the outer surface, a crust, which has fully cooled and is incapable of further contraction, and in the centre a heated core, to which cooling has not penetrated; between the two lies a belt of material which is gradually losing heat and contracting in bulk. At the inner limit the contraction of this layer of cooling material must cause tension, as a diminution of the circumference is resisted by the uncooled central core; at the outer limit, where no further cooling takes place, the consolidated crust would be thrown into compression by the reduction in bulk of the material below, and somewhere between these two would come a zone where the radial and tangential contractions exactly balance each other, so that the material would neither be compressed nor extended.

The depth at this level of no strain beneath the surface would depend on the initial temperature of consolidation and the temperature gradient. The latter is approximately known, the former is doubtful; Mr. Mellard Reade, assuming a temperature of about 3,000° F., calculated the depth at about 1 mile; later, Mr. Fisher calculated a depth of about 0·7 mile for an initial temperature of 4,000° F., and of 2 miles for an initial temperature of 7,000° F. Of these three values for the initial temperature the lowest is the most probable, and the calculations show that any rift, which might be formed by tension in the 'sub-crust', could not reach the surface; it would originate at the level of the greatest tensional strain, which would lie at between 30 and 50 miles below the surface, and thence extend upwards and downwards, but could not reach upwards to within about a mile from the surface. These calculations never had any geological interest, beyond showing that the hypothesis of an originally highly heated, and gradually cooling, solid globe afforded no sufficient explanation of the structure of the earth's outer crust, as revealed by geological observation in the field; they have been rendered of little more than academic and historic interest by modern researches in radio-activity, which have, incidentally, provided a means by which fissures opening at the surface of the earth and penetrating downwards could be produced; for if the earth is an originally cold globe, getting gradually warmer, and expanding in bulk, by the action of radio-active material, then such fissures would naturally be formed; but in that case none of the consequences which Colonel Burrard has drawn from his rift would follow.

In all this I have not been arguing for or against a fluid or a solid earth, but against the introduction of an irrelevant issue. Whether the earth is a fluid or a solid globe seems a matter which concerns the astronomer, the physicist, or the mathematician, much more than the geologist; for all the processes which his observations demand appear to be equally compatible with either hypothesis. Nor am I arguing against Colonel Burrard's explanation as a whole; it may stand with the others as a possible hypothesis, to be tested and examined on its merits, but the tests must mostly be of a nature quite unconnected with geological observation. When, however, Colonel Burrard postulates the existence of a rift, or narrow band of subsidence, reaching 20 miles deep from the surface, we are brought face to face with a phenomenon for which we have no precedent, and before accepting it we must be satisfied, not only that it explains the geodetic facts, but that no other explanation, in closer accord with what is known of the geology of the regions, can be found.

No one can gainsay Colonel Burrard's contention that geologists must take count of the facts of geodesy, but it is equally true that

[1] Sir T. H. Holland, "Origin of Himalayan Folding": Geol. Mag., 1913, p. 167.

[2] Rev. O. Fisher, "Rigidity of the Earth," Geol. Mag., 1913, p. 250; "Origin of Mountains," Geol. Mag., 1913, p. 434.

[3] Colonel S. G. Burrard, "Origin of Mountains": Geol. Mag., 1913, p. 385.

geodesists must take count of the facts of geology, and in either case a distinction must be drawn between the facts of either science and the conclusions of individual workers, and again between those direct and inevitable deductions, which have almost the value of observed facts, and the more remote inferences, which may represent only one, or a part of one, of the possible explanations. Bearing this in view I propose to review, very briefly, the facts and explanations on either side.

On the geodetic side the facts may be summarized by taking the two stations Kurseong and Jalpaiguri, 25 miles apart, the first situated on the edge of the Himalayas, the second out in the Gangetic alluvium. At Kurseong the observed deflexion of the plumb-line is 46″ to the northwards; the calculated effect of the attraction of all visible masses, after allowance is made for the effect of isostasy, should have produced a deflexion of only 23″, leaving an unexplained residual of 23″ northerly deflexion. At Jalpaiguri the observed deflexion is only 1″ to the northwards; the calculated deflexion should have been 8″ to the northwards, leaving an unexplained residual of 7″ southerly deflexion. It may be well to point out that the values, both of the observed deflexions and of the unexplained residuals, depend on the assumed dimensions of the earth. The figures quoted are deduced from the dimensions now accepted by the Great Trigonometrical Survey of India as the nearest approach which has been made to exact accuracy, but, although the acceptance of different values for the size of the earth would alter the figures, no admissible variation would make a material change in the difference between them. For instance, if the earlier values, based on the Everest spheroid, are adopted, the observed deflexions at Kurseong and Jalpaiguri become 51″ and 6″ to the north and the unexplained residuals 28″ to the north and 2″ to the south, still leaving a difference of 30″ as between the two stations, which cannot be explained by the ordinary methods of geodetic calculation, and is only to be accounted for by some local peculiarity, or departure from average conditions. The explanation offered by Colonel Burrard is a deep and narrow rift, filled with material of less density than average rock, and situated between the two stations; there can be no question that the explanation is a feasible one, so far as the mathematics are concerned,[1] for the diminished attraction caused by the replacement of denser by less dense material would cause an apparent repulsion on either side of the rift, but before accepting this as the only, or even as the probable, explanation, we must see whether another cannot be found, in better accord with the known facts of geology.

The geological facts, which are pertinent to the question under consideration, may be simply expressed. All along the southern face of the Himalayas runs a great fault, or series of parallel faults, known as the boundary fault, on the north of which lie the older rocks of the Himalayas, and on the southern the upper Tertiary

[1] It may be added that a much lesser depth than 20 miles would not satisfy the conditions.

Siwaliks of the sub-Himalayas and the alluvium of the Gangetic plain. The Siwaliks were long ago shown, by Mr. H. B. Medlicott, to have been formed from the waste of the Himalayan range, under exactly similar conditions, and by the same rivers, as the alluvial deposits of the Gangetic plain, in other words to be merely the lower, older, and marginal, deposits of the same formation, now uplifted and exposed to denudation. The throw of the boundary fault cannot be measured directly, but it is certainly great, and may reasonably be estimated at between 10,000 and 15,000 feet, say between two and three miles. It may exceed or fall short of these limits in places, but is not likely to do so to any material degree.

On its southern margin the alluvium thins out over an old land surface. Between the two margins nothing can be determined, by direct observation, of the form of the rock floor, but the most natural deduction is, that the thickness of alluvium gradually increases from south to north, reaching its maximum at the great boundary fault, so that the Gangetic trough may be regarded as having the form of a very acute-angled wedge lying on its side, with the thick end towards the north. Mr. H. H. Hayden has recently shown that the pendulum observations of the Indian Survey support this interpretation,[1] but whether this exactly represents the case or not it is certain that the northern limit of the Gangetic trough is nearly vertical and of a depth of two or three miles, while at the southern limit the thickness of the alluvium is very small.

The effect on the direction of the plumb-line of a depression of this size and shape, filled with material which cannot have a density of more than 2·2, must be considerable, and I have had the curiosity to investigate it. The detailed results of the investigation would take up too much space to reproduce them here, nor are they suitable to this Magazine, but the general result may be indicated. I find that at the northern limit of the plain the effect would be an apparent repulsion of the plumb-bob, or in other words an apparent excess of attraction by the Himalayas, amounting to about 30″ if the depth of the alluvium is taken at 3·5 miles, and 18″ if it is taken at 1·75 miles. These values are not materially affected by any variation in the width of the alluvium. On either side of the boundary fault the deflexions decrease rapidly, but more rapidly to the south than on the north, for whereas, at 20 miles from the boundary on the north, there is still a deflexion of some 5″ or 6″ to the northwards, the northerly deflexion has almost disappeared at the same distance to the south, to be replaced, still further south, by a southerly deflexion, or apparent repulsion away from the Himalayas.

I have only indicated here the general nature of the effect which would be produced, but enough has been said to show that both in kind and magnitude it is very similar to that which has been observed, and for the explanation of which the 20 mile deep rift has been offered. Kurseong lies about 2 miles north of the main boundary fault, Jalpaiguri lies in the region where southerly deflexions should be expected, and the difference in deflexion, as

[1] Rec. Geol. Surv. Ind., xliii, pt. ii, pp. 163–7.

between the two stations, due to the effect of the less dense material filling the Gangetic trough, could not be less than 20″ and might amount to over 30″. From this it appears that without going beyond the known facts of the geological structure of the region—facts which are independent of any theory of the origin of mountains or the constitution of the interior of the earth—we can account for nearly, if not quite, the whole of the unexplained residual deflexions, which, instead of amounting to 23″ and 7″, would not come to more than 3″ or 4″, and the difference of 30″ would disappear or, at the least, be reduced to one of a few seconds of arc.

In all that has gone before I have avoided the question of the origin of mountain ranges in general, or of the Himalayas in particular, as, although I entered on the investigation, which I hope to publish in detail, with the hope that the limit of fairly established deduction might be carried further into the domain of pure speculation, I have found that the geodetic results do not give any material assistance. They have confirmed some conjectural inferences regarding the form of the rocky bed of the Gangetic depression, but on the question of the origin of the Himalayas, and of the nature of their support, the evidence is too uncertain and equivocal to be of any material value. This much, however, seems certain, that there is no good evidence for the existence of a rift of 20 miles or so in depth, as, once the known facts of geological structure are taken into consideration, the existence of such a rift would explain too much and introduce fresh difficulties even greater than those for which it was introduced as an explanation. Moreover, we must add to this negative evidence the positive fact that every observer, in every part of the range which has been visited, has found evidence of compression in precisely that zone where Colonel Burrard's postulate demands extension.

III.—The Plutonic Rocks of Garabal Hill.

By B. K. N. Wyllie, M.A., B.Sc., and Alexander Scott, M.A., B.Sc., Carnegie Research Scholars in the University of Glasgow.

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At various places, such as the north side of Garabal Hill, the two Garabal burns (loc. iv and v, Fig. 1), and elsewhere, remarkably coarse rocks are found. A good section showing an apparent passage from tonalite to a coarse hornblendite is exposed at loc. v (Fig. 1). The rock in the bed of the burn is the normal tonalite, which appears to pass gradually to diorite. A closer examination of the unweathered rocks, however, shows that the passage is only apparent, and that the tonalite is clearly intrusive into the diorite with sharp junctions. The diorite near the junction is a rock of porphyritic aspect, containing large crystals of zoned diopside, abundant green hornblende and felspar, while the amount of quartz is small. A good deal of biotite is present, so that the rock might be described as a pyroxene-mica-diorite. Within a few feet the rock becomes coarser in texture, and the felspathic content diminishes, while there is a corresponding increase in the amount of amphibole. The latter is the green hornblende common to the diorites, and is occasionally replaced by mosaics of secondary actinolite. This substitution of felspar by hornblende, accompanied by an increase in the coarseness of the texture, continues till a hornblendite containing about 85 per cent of amphibole is reached. This rock is exposed for a distance of 20 yards to the south, and then the ground is obscured by peat, so that the other margin of the diorites cannot be seen. The hornblendite consists essentially of large crystals, more or less uniform in size and up to 3 cm. in length, of green hornblende which has wholly or partly altered to brown, the alteration commencing invariably from the centre. Occasional pyroxene cores are found, and these are generally surrounded by a narrow band of green amphibole, with brown beyond and finally green margins. The interstices are filled up with aggregates of quartz, felspar, and small green hornblendes, with occasional crystals of sphene. The finer-grained varieties of this sequence probably resembled very much the hornblendite which occurs along with scyelite in the Moine Gneiss regions.[1] Occasional schlieren, resembling those already described, occur among the coarser rocks. These are generally much more felspathic than the surrounding rocks and contain long prismatic hornblendes up to 6 cm. in length.

The brown hornblende of this series differs considerably from that of the davainites. In the latter case the mineral has developed directly from pyroxene and is invariably brown, while in the former case it has formed from original green hornblende, different degrees of transformation being visible, varying from incipient alteration at the centres to completely brown crystals. The mineral shows pleochroism from deep brown to yellowish green and has strong absorption. It is generally traversed by series of parallel dark bands arranged in lattice fashion and with small outgrowths, the whole somewhat resembling arborescent microlites. Teall[2] has described similar structures in amphiboles from Cornwall and Anglesey, and Thomson[3] also found them in hornblendites from Wicklow. In these cases the dark bands were assumed to be magnetite, formed by the magmatic resorption of pyroxene and consequent replacement by hornblende. In the Garabal Burn rock a careful examination, under a high power, of the ends of the bands and outgrowths showed that they are composed of aggregates of minute pale-green or colourless crystals, orientated in irregular fashion with respect to the main direction of the bands. It seems probable that the whole of the dark bands are made up of these minute crystals, the black colour being analogous to that observed in some opaque glasses, where the opacity is due to innumerable colourless longulites, which act as prisms and disperse and totally reflect the light, the degree of opacity varying with the amount of light totally reflected.[4]

[1] *Geology of Ben Wyvis*, etc. (Mem. Geol. Surv. Scotland), 1912, pp. 128–9.
[2] *British Petrography*, 1908, pp. 475–94.
[3] Quart. Journ. Geol. Soc., lxii, pp. 475–94, 1908.
[4] Cf. Pirsson, "Artificial Lava Flow and its Spherulitic Crystallisation": Amer. Journ. Sci., ser. iv, xxx, pp. 97–114, 1910.