To ....

With the Author's compliments.

ON THE GEOLOGICAL INTERPRETATION OF SOME RECENT GEODETIC INVESTIGATIONS (BEING A SECOND APPENDIX TO THE MEMOIR ON THE STRUCTURE OF THE HIMALAYAS AND OF THE GANGETIC PLAIN AS ELUCIDATED BY GEODETIC OBSERVATIONS IN INDIA).

BY

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SINCE the appearance of the Memoir on the Structure of the Himalayas, and of the Gangetic Plain, as elucidated by Geodetic Observations in India[1] and the Appendix on the Support of the Mountains of Central Asia,[2] other contributions to our knowledge of the subject have been published, of which three appear to require special consideration. Two of these have been issued by the Survey of India, and contain the results of a large amount of computation, having important bearings on the problem of the origin of the Himalayas and, incidentally, on the wider one of the origin of mountains in general.[3] The third is an important study of the question of compensation and isostasy by Prof. A. Alessio, which contains also the results of the observations of gravity and deflection of the plumb line, made in the course of the Filippi expedition to Central Asia.[4]

Had Col. Cowie's 'criticism' been no more than its title indicates, no useful purpose would be served by a merely controversial rejoinder, but, in addition, it contains some important results of computation. The criticisms are numerous and detailed, in some cases they deal with mere slips of the pen or printer, in others they point out real mistakes, and in others again it is Col. Cowie who is in error. So far as they refer to matters of detail, I do not propose to deal with

[1] *Mem. Geol. Surv. Ind.*, Vol. XLII, pt. 2 (1917).

[2] *Rec. Geol. Surv. Ind.*, Vol. XLIX, pp. 117-135 (1918).

[3] Colonel Sir S. G. Burrard, "Investigation of Isostasy in Himalayan and neighbouring Regions." *Surv. Ind. Prof. Paper*, No. 17 (1918).

Lieut.-Col. H. McC. Cowie, "A criticism of Mr. R. D. Oldham's Memoir. The Structure of the Himalayas, and of the Gangetic Plain as elucidated by Geodetic observations in India." *Sur. Ind. Prof. Paper*, No. 18, 1921.

[4] Prof. Alberto Alessio. "Dubbie Idee sull'isostasi terrestre." *Rivista Marittima*, March 1922, supplement.

them ;[1] but a few matters of principle may well be noticed, before passing on to the consideration of the fresh information contained in his paper.

At the outset he states that " Mr. Oldham .....appears..... to be of the opinion that we need look no further than the Gangetic Trough, filled with alluvium, for the explanation of the anomalies of the plumb-line deflection and intensity of gravity. " Further on he adds, " the aim of the Memoir is, perhaps, the evolution out of the material afforded by geodetic determinations, of the shape of the trough rather than the solving of the problem presented by the gravitational anomalies.''[2] The " perhaps ' of the latter of these two quotations was quite explicitly and avowedly one of the main purposes of the Memoir, and the passage first quoted is the more remarkable as I had endeavoured to show that neither the deflections and anomalies, nor the residuals left after allowing for compensation, could be wholly accounted for by the lessser density of the Gangetic alluvium, and that some other, additional, cause must be invoked. This conclusion may not have been sufficiently clearly developed in the text but it is quite clearly and definitely claimed in the summary at the end of the memoir.[3] The matter had to be considered because this explanation had been suggested by an authority,[4] whose other ideas have been widely accepted and had never been tested, for confirmation or the reverse.

The next point to be considered is the criticism of the use made of the Imaginary Range. Col. Cowie shows that the computed effect at certain stations differs from that derived from actual topography by amounts which are very material, from the geodetic point of view. This is true and natural, but the criticism does not touch the purpose or use made, of the concept, the argument throughout the Memoir being from the differences in effect at stations in the same region ;

[1] I may except the criticism, on pp. 8-9, of the statement in the Memoir that the observations of deflection at Gogipatri and Poshkar might be accepted as correct within one second of arc. The statement in the Memoir was made on the authority of the then Surveyor General, of whom I had enquired as to the reason for the exclusion of these observations from the final account, and the extent of the uncertainty of the determinations. In reply to this enquiry, I w. s courteously informed that the omission was due to the unfavourable weather conditions prevailing at the time, making the observations of less precision than was demanded by the Trigonometrical Survey, and that the error was not likely in any case to exceed one second of arc. It is not a matter on which I should frame an independent opinion.

[2] *loc. cit.* p. 2.

[3] *loc. cit.* p. 136. See also figs. on pp. 115, 125 and explanatory text.

[4] Suess, " Das Antlitz der Erde," Vol. III, pt. 2, chap. 26.

to calculate these from the actual topography would be impossible for anyone unprovided with the resources of a properly organised computing office, and it seemed that an approximation, at any rate, to the order of magnitude of the differences, sufficiently close for the purpose of the investigation, could be obtained by assuming a simplified topography, which would simplify the calculations. For this purpose, the method seemed, and seems, justifiable, and no suggestion was made that it should be adopted for any other purpose, nor the results used in any other way.

Finally there is Col. Cowie's criticism and discussion of the centre of effect. He discusses in detail the question of whether, in a column of small cross section and considerable length, there could be any point at which the whole mass might be considered to be concentrated, so that the resultant attraction, at any given station, would be the same as that of the same mass distributed through the column. No such claim was, however, made in the Memoir; what was there asserted was that in any such vertical column there must be a point at which, if the mass were concentrated, the horizontal component of its attraction, or otherwise its effect on the plumb line, would be the same as that of the same mass distributed through the column. That there must be some such point does not need elaborate demonstration, for if the whole mass were concentrated at the upper end of the column, the deflection produced would obviously be greater, and if concentrated at the lower extremity, less, than if distributed throughout the column; from this it follows that, somewhere between the two extremes, there must be a point where the effect would be the same, and this is equally true whether the density is, or is not, uniform throughout the column. Similarly there must be a point where, if concentrated, the attraction of the mass would have the same vertical component, or effect on the pendulum, as the same mass distributed through the length of the column. The question of whether these two centres of effect are, or are not, coincident was not considered, as it was not pertinent to the use made of them, but it is easy to see that, where the horizontal distance is small, compared with the vertical depth of the column, they must materially differ in position, from each other, from the centre of effect as dealt with by Col. Cowie, and from the centre of gravity of the column, and that, as the distance separating the column from the station increases, these four points will approach more closely to each other.

The principal object for which the concept was introduced was to examine into the effect which would follow on a change in the distribution of compensation. Near the edge of the hills there were large residuals of deflection and anomaly, one possible explanation was a difference in the distribution of compensation under the plains and the hills; this had never been investigated or a numerical estimate formed, and it seemed that by treating the compensation in this simplified manner a useful idea could be formed of the order of magnitude and distribution of the corrections to the residuals, which would be reached in this manner. The method was applied and showed that neither in amount, nor distribution, was the modification such that more than a small fraction of the residuals could be so accounted for; but the method was definitely put forward, as a purely preliminary trial to see whether a more detailed examination of the question was needed; for this purpose, and within these limits, it seems justifiable, nor is there any novelty in it. In principle it is identical with Helmert's method of condensation, though in his case the treatment was necessarily less simple, as greater precision of result was aimed at, than was needed for the purpose of the Memoir.

It will be seen, then, that the criticisms are largely based on misconception, yet this is not to be regretted as it has led to important additions to our knowledge, and we have now detailed calculations at a number of stations which were not available when the Memoir was being written. The result of these calculations is that the approximate methods there used, which were justifiable and necessary in 1914, are no longer needed; the effect of topography, compensation, and of the alluvium has now been computed in detail at a sufficient number of stations to allow of the results being used directly, in testing those of the conclusions, set forth in the Memoir, which bear on the origin of the Himalayas.

The calculations deal with the geodetic effect of an alluvium-filled trough, such as is indicated by geological evidence, and seems to be supported, or at least not contradicted, by geodetic observations. For the purpose of these computations Col. Cowie has prepared a map which purports to, and in the main does, show the form and dimensions of the trough, as deduced in the Memoir. The depths of alluvium are shown with greater precision than I should have been prepared to do, for throughout the Memoir it is distinctly stated that the figures given can only be taken as good indication of the relative depths in different portions of the trough, representing no more than the order of magnitude of the absolute depths ; this precision of statement is, however, essential to numerical calculation, and the general form is in accordance with the conclusions of the Memoir, except that the ridge separating the two deeps is placed a little further east than I should put it. The northern boundary does not follow exactly that shown in the map attached to the Memoir, as it follows neither the boundary of the alluvium, nor that of the Siwalik rocks ; from the Dehra Dun eastwards it follows the former, to the westwards it trespasses on the Siwalik area and includes a portion, but not the whole, of that strip of lighter rock fringing the area occupied by the older and denser rocks of the Himalayas. On the south the boundary agrees with mine at both ends, but in the middle departs considerably from it. The southern boundary of the deep alluvium is shown in the Memoir a little northwards of Delhi, thence curving on both sides to meet the general course of the boundary ; Col. Cowie obliterates this imbayment and carries the boundary in an even sweep across the Aravalli hills, placing it, at one place, some 60 miles from the position shown on the Memoir map, and indicating a depth of over 5,000 feet of alluvium where the geological map clearly shows that rock is exposed at the surface. This error, unfortunately, comes in just where the series of stations treated is most complete ; the result is that at three of them, Noh, Agra and Usira, the computed effect is greater than that which would result from the conditions indicated in the Memoir, but the absolute effect of the divergence is small as the southerly deflections at these stations computed by Col. Cowie, amount to only 1″, 2″, 1″, respectively. At other stations the effect of the difference in the boundary adopted is even smaller, and negligible in comparison with the uncertainty in the vertical dimensions made use of ; yet in a work which takes objection to approximate methods, it would have been well to obtain a degree of precision in the fundamental data of computation, which could have been secured by anyone familiar with the interpretation of geological maps.

Besides the effect of the alluvium, there is that of the lesser density of the Siwalik rocks, which has not been considered by Col. Cowie, though it would be quite appreciable at three of his stations, Mussoorie, Dehra Dun and Birond. At Mussoorie the effect has been computed by Sir S. G. Burrard[1] as—3″ ; at Dehra Dun he gives no separate estimate, but with the dimensions of the tract and the

[1] *loc. cit.*, p. 35.

position of the station it would not be materially different from the same value; at Birond the width of the Siwalik tract is about half that of the Dehra Dun region, but as the station is nearer to the boundary, the net effect may be taken as somewhat less than at Mussoorie or say—2″. All these values depend on the supposition that the surface of separation between the Siwalks and the older rocks slopes steeply, at an angle of over 45° from the horizontal; if the dip of the contact is much less than that the effect at Mussoorie and Birond would be greater, and at Dehra Dun less, than these figures, but the change would not be more than a fractional part of them.

Even with these additions Col. Cowie's figures prove conclusively that the peculiarities of the residuals of attraction in the neighbourhood of the margin of the mountains can only partially be attributed to the effect of the lesser density of the Gangetic alluvium. This may be seen from the figures reproduced in the table No. I,

TABLE I.

Deflections, and Residuals of deflection, at stations over and near the Gangetic Alluvium, as deduced by consideration of an alluvial trough in addition to surface masses, by Col. H. McC. Cowie.

Station.	Observed deflection.	CALCULATED EFFECT OF TROUGH ALONE.		CALCULATED DEFLECTIONS SUPPOSING.		RESIDUALS.	
		Uncompensated.	Compensated.	No trough.	A trough*.	Cols. 2—5.	Cols. 2—6.*
1	2	3	4	5	6	7	8
	″	″	″	″	″	″	″
Lambatach . .	—27	—5	—1	—9	—11	—18	—16
Mussoorie . .	—30	—7	—2	—17	—20	—13	—10(—7)
Dehra Dun . .	—31	—6	—2	—18	—20	—13	—11(—8)
Kaliana . .	—1	0	+1	—3	—2	+2	+1
Bangsopal . .	+1	+1	+1	—1	—1	+2	+2
Noh . . .	+5	+4	+1	—1	+1	+6	+4(+5)
Agra . . .	0	+5	+2	0	+2	0	—2 (0)
Usira . . .	—1	+4	+1	0	+2	—1	—3(—1)
Kesri . . .	+10	+2	0	+1	+1	+9	+9
Panurgarh . .	+4	+2	0	+1	+1	+3	+3
Birond. . .	—38	—12	—5	—14	—21	—24	—17(—15)
Pathardi . .	—14	—12	—6	—3	—10	—11	—4
Nimkar . .	+5	+4	+2	—1	+1	+6	+4
Sora . . .	+11	+10	+4	0	+4	+11	+7
Kanakhera . .	+10	+8	+2	0	+3	+10	+7
Siliguri . .	—18	—3	—1	—11	—13	—7	—5
Jalpaiguri . .	—1	—2	—1	—8	—9	+7	+8
Chanduria . .	+9	+3	+1	—2	—1	+11	+10

* Figures in brackets represent residuals after allowing for the effect of the Sivalik tract, and of difference between Col. Cowie's trough and that of the Memoir, as referred to in the text.

where three groups, forming three cross sections, are arranged each in order of increasing distance from the main axis of the Himalayas. For each station there is given, the observed deflection, the computed effects of the visible topography and of the assumed alluvial trough and the residuals before and after allowing for the decrease in density of the alluvium of the Gangetic plains; in the last column I have added, for the three stations referred to above, the residual as it would be if the effect of the Siwalik tract were also considered; and at three others, Noh, Agra, and Usira, the probable values, if the southern contours of the trough had been in accordance with the form indicated in the Memoir and by geological survey.

The figures show that, after allowing for the effect of the alluvium there are still large northerly residuals in the outer hills to the north of the alluvium, and large southerly residuals in the rock area to the south. The former of these disappear rapidly near the edge of the hills and give place to southerly deflections; it was to account for this that Sir S. G. Burrard suggested the existence of a 'rift' or belt of material of less density than the average of the material on either side. So long as deflections only are considered it is a feasible explanation, and it would be possible to work out numerically the dimensions and deficiency of density, which would be necessary to fit in with observation, but it is not consistent with the co-existence of large residuals of positive anomaly and northerly deflection in the outer Himalayas. The latter is an important objection, it does not make the existence of the 'rift' impossible, but it shows that this can at best be only a partial explanation, and that there must be some other cause of the peculiarities shown by the residuals of anomaly and deflection.

One such cause was suggested in the Memoir[1] and may be briefly reconsidered. The principal is represented diagrammatically in the Fig. 1, where the dotted line may be taken to represent what would be the

FIG 1.

[1] *loc. cit.*, p. 115, fig. 8; p. 127, fig. 10.

surface if, the portion to the right having been uplifted, the principle of isostasy had been completely effective at every point, and compensation completely in accord with the surface inequalities of elevation and depression; and, assuming a certain degree of rigidity in the outer crust, combined with some capacity of yielding in the underlying material the firm line might represent the real surface contour, so that at A the surface stands too high, at B and C too low, and at D too high, to correspond with that underground variation in density, which would give an ideally perfect compensation. The effect of this divergence between the actual surface and the surface of equilibrium, on the pendulum and plumb line is indicated by the arrows; at A, corresponding to the hills south of the alluvium, there would be positive anomalies accompanied by southerly residuals of deflection, at B negative anomalies and southerly residuals of deflection, at C the anomaly is still negative but the residual of deflection northerly, and at D the northerly residual of deflection is accompanied by a positive anomaly. At E the actual would lie below the ideal surface and negative anomalies would be combined with southerly residuals of deflection. The evidence of this combination is not complete in the Himalayas, but its presence is suggested by recent observations, and apart from this the sequence deduced from the hypothesis agrees with that which is actually observed, and consistently exhibited, by all the stations, from the northern part of the Peninsula to the outer edge of the Himalayas. It would be possible to work out the amount, and variation, of departure from the level of equilibrium, which would most closely agree with observations, and doubtless to obtain a very close agreement, but no useful purpose would be served by such calculation for it would only be stating the same hypothesis in figures instead of words; at most it would give one possible solution of the problem, of which many others may be equally possible.

Some further evidence bearing on this question may be derived from Sir S. G. Burrard's investigation, which has been mentioned above. In this he takes the residuals at a number of stations, on the alluvium and in the rock areas to the north and south of it and then computes the depth of alluvium which should exist in the trough, if the whole of these residuals are attributed to the effect of the deficiency of mass in the alluvium, and the excess in its compensation. The result is given in the form of the mean depth of alluvium which would produce the required effect, but the details of results at each station show that the method followed was to compute the deficiency of mass, in the form of the thickness of rock of average density, and to convert this into depth of alluvium, adopting a density of 2·4. The density of the alluvium not being relevant to the present purpose, which is only concerned with the defect of mass, it will be convenient to reconvert the figures given into the form of the equivalent deficiency in mass, expressed as thickness of rock of average density.

The results of the investigation are summarised in a series of tabular statements, each dealing with a separate cross section of the trough, the results obtained from pendulum and plumb-line observations being given in separate columns, and the stations classified in three groups according as they are situated over the trough, to the north, or to the south of it; an average is struck for each group and a general average of the whole is made.[1] The procedure is sound enough for some purposes, but, in making use of the results for elucidating, and extending, the conclusions to be drawn from geological observation, a somewhat different treatment will be more instructive. I have, therefore, rearranged the figures in a form which will enable an average to be struck for each of the three groups of stations, and for each of the two forms of geodetic measurement.

For this purpose I have used the original figures given in the detailed account of the various stations considered, instead of the summary, as the latter exhibits three discrepancies, one trivial but the other two material. In the central section, No. IV, there are two entries, one for stations north of, and the other for those over, the trough; reference to the details show that these figures refer to the stations Mussoorie and Dehra Dun, but the latter is not properly a station over the trough, being situated near the inner boundary of the Siwalik tract, and therefore to the north of the alluvial trough. At Mussoorie two separate estimates are given, firstly, after allowing for the effect of the deficiency in density of the rocks of the Siwalik tract, it is estimated that the deficiency over the trough itself amounts to the equivalent of 8,000 feet of average rock and, secondly, an estimate of the mean deficiency, taking the Siwalik tract as part of the trough, which works out at 2,500 feet. In the summary the latter is used, but the adoption does not seem justifiable, if the object is to measure the deficiency over the trough proper, which would account

[1] *loc. cit.*, pp. 15-17.

for the residual of deflection: for this reason I have adopted the former, in preference to the latter value. In the case of Dehra Dun only one estimate is given, in which the Siwalik tract is included with the alluvial trough; here also the proper course would be to consider the effect of the Siwalik tract separately, and then frame an estimate of the required deficiency over the alluvial trough. As this has not been done it is not possible to say more than that the resulting average deficiency over the trough would probably be rather less than at Mussoorie; the effect of the Siwalik tract would be about the same at the two stations, the residual to be accounted for would, consequently, be the same, but the station lying somewhat nearer to the trough, the deficiency required would be less. I have adopted 7,000 feet as an approximate figure, based on the estimate of 8,000 for Mussoorie.

Arranged in this manner the stations, at which estimates could be framed, are shown in the tabular statements Nos. II and III giving, respectively, the figures for the plumb-line and the pendulum observations, and the mean values for each group of stations.

TABLE II.

Estimated deficiency of mass, over the Gangetic trough expressed in feet thickness of rock of average density, which would account for the residuals of deflection (after Sir S. G. Burrard).

No. of Section.	Stations north of the trough.		Stations over the trough.		Stations south of the trough.	
I	Kurseong . .	5,000	Chanduria . .	6,000		
II					Hurilaong . .	7,500
					Chenduar . .	6,000
III	Birond . . .	5,000				
			Gurwani . .	15,000		
IV	Mussoorie . .	8,000				
	Dehra Dun . .	7,000				
V			Amritsar . .	7,500		
Means.		6,250		9,500		6,750

TABLE III.

Estimated deficiency of mass, over the Gangetic trough, expressed in feet thickness of rock of average density, which would account for the anomalies of gravity (after Sir S. G. Burrard).

No. of Section.	Stations north of the trough.		Stations over the trough.		Stations south of the trough.	
I	Sandakphu . .	7,000				
			Siliguri . .	3,000		
			Jalpaiguri . .	2,000		
					Kisnapur . .	7,000
II			Gorakhpur . .	0,000		
			Majhauli Raj .	5,000		
			Muzaffarpur .	4,000		
			Arrah .	7,000		
					Ranchi	10,000
IV	Mussoorie . .	6,000				
	Rajpur . . .	4,000				
	Dehra Dun . .	4,000				
			Roorkee . .	3,500		
			Kaliana .	1,200		
			Gesupur . .	1,200		
V			Pathankot .	5,000		
					Mian Mir . .	7,000
Means .		5,250		3,800		8,000

The most conspicuous feature in these figures is the want of accord between the results obtained from the different groups of figures, and different means of observation. The plumb-line observations over the trough give higher figures, by nearly one-half, than those in the regions to the north and south, and in the case of the pendulum, a discrepancy in the opposite direction. If the results from the two different forms of observation are averaged, the means come much closer into agreement with each other, the figures being a deficiency of, in round numbers, 5,800 feet from stations north, 6,700 feet from stations over, and 7,400 from stations south of the trough, but the justification of this method is very doubtful, owing to the different degrees of trustworthiness in the different groups of stations of the figures obtained from the two methods of observation. Over the trough the effects, both of the deficiency of density in the alluvium and of the excess in the compensation, are nearly directly under the station and will, therefore, be more direct and effective in the case of the observations of the pendulum than of the plumb line. In the case of stations outside the trough the reverse is the case, the effect being more direct on the plumb line than on the pendulum.[1] An arithemetical mean of the two would, therefore, not be correct, a weighted mean should be used but it would be difficult to give proper weights to the values derived from the different methods of observation. In the case of stations outside the trough a ratio of 2 : 1 might be sufficient, but over the trough it should be larger, to what extent it is difficult to say. Probably the safest method would be to take the plumb-line observation for stations outside, and the pendulum observation for those over the trough ; in this case the figures would be 6,250 and 6,750 for stations north and south of the trough, and 3,800 for those over it.

The magnitude of the discrepancy suggests that the supposition, on which the calculations are based, is at fault and that part only of the residuals in the regions outside the trough, or in the region over the trough, are due to the deficiency of mass represented by the lesser density of the alluvium, the remainder being due to some other cause ; or it might be that this other cause was operative in opposite directions in the region over the trough, and in those outside of it. One such cause, which could produce the desired effect, would be a departure from the level of equilibrium, between topography and compensation, such as has been suggested.

The discrepancies shown by the mean values come out with equal or greater conspicuousness when the pendulum observations, which give a more or less complete series on the sections I, II and IV, are considered. In all of these three the discrepancies in the

[1] The mean width of the trough is about 120 miles, the maximum depth being at about 40-50 miles from the northern edge, and the depth of compensation assumed is about 70 miles. From this it follows that the resultant attraction at stations outside the trough would be inclined at angles less than 45° from the horizontal at stations outside the trough, and more than 45° at stations over the trough, the excesses and defects being, on the average, very considerable. The vertical component is, consequently, the more effective at stations over the trough, and the horizontal at stations to the north or south of it.

amount of the deficiency deduced, and the systematic character of the variation, could be accounted for by the adoption of an hypothesis of alternate zones of super-elevation and depression, as suggested in the Memoir, which would tend to equalise the estimates of the deficiency of mass in the alluvium by reducing the larger and increasing the smaller. Without going further into this matter, it is enough to point out that the discrepancies at least establish the same conclusion as is proved by Col. Cowie's calculations, that the residuals, of deflection and anomaly, cannot be attributed solely to the effect of the alluvium, but must be in part due to some other cause or causes.

Before dealing with the third of the new contributions of knowledge, mentioned at the outset, it will be well to recall that part of the Memoir which points out that if the suggested cause, for the alternate belts of super elevation and depression, is accepted we should expect that the excess of mass in the outer Himalayas would not continue over the whole range, but would disappear in the interior, and possibly be replaced by another belt of defect, marked by negative residuals of anomaly. At the time when the Memoir was undertaken no observations were available except the somewhat uncertain one by Basevi, at Moré. It was pointed out that this indicated a Bouguer anomaly of about —·43 dyne, and, by a process of extrapolation, a perfectly justifiable method when used with discretion, it was concluded that the allowances to be made for compensation would be of about the same magnitude.[1] Since then this allowance has been computed in detail, the result has been announced by Sir S. G. Burrard in an indirect form,[2] the Bouguer anomaly being given as —·419 and the Hayford as +·018 dyne; the discrepancy between the Bouguer value, as given in the Memoir and by Sir S. G. Burrard, is easily accounted for, and need not be considered further, as it is not greater than the inherent uncertainty of the observation; but the difference between the Bouguer and Hayford anomalies gives the allowance for compensation as +·437 dyne. This figure will be useful when considering the observations made by Prof. Alessio in the course of the Filippi expedition to Central Asia.

[1] See *loc. cit.*, p. 113.
[2] *Geog. Journ.*, Vol. LVI, p. 49 (1920).

TABLE IV.

Deflection of the plumb line, determined by Prof. A. Alessio on the Filippi expedition to Central Asia.

Station.	Lat.		Long.		Elev.	Deflections.	
	°	′	°	′	m.	″	″
Rimu	35	21	77	39	4,012	9·8 N	
Dipsang	35	17	77	58	5,359	2·0 N	5·8 E
Leh	34	10	77	35	3,579	14·5 N	10·5 E
Lamayuru	34	17	76	46	3,450	6·3 S	0·2 W
Kargil	34	34	76	7	2,713	0·9 N	9·9 W
Skardo	35	18	75	39	2,233	28·3 S	10·9 E
Vozul Hadur	35	12	75	32	4,243	25·7 S	

TABLE V.

Gravity observations by Prof. A. Alessio on the Filippi expedition to Central Asia.

Station.	Lat.		Long.		Elev.	g*	YB	g—YB*
	°	′	°	′	m.	dyne.	dyne.	dyne.
Kashgar	39	28	75	59	1,312	979·537	979·860	—·323
Yarkand . . .	38	24	77	16	1,200	9·530	9·988	—·458
Sujet Karol . . .	36	21	78	2	3,658	8·741	9·166	—·425
Dipsang	35	17	77	58	5,359	8·165	8·700	—·535
Leh	34	10	77	35	3,519	8·529	8·967	—·438
Lamayuru	34	17	76	47	3,450	8·575	8·990	—·415
Kargil	34	34	76	7	2,713	8·845	9·158	—·313
Skardo	35	18	75	39	2,233	8·929	9·315	—·391
Vozul Hadur . . .	35	12	75	32	4,243	8·536	8·911	—·375
Tolti	35	2	76	6	2,409	8·853	9·259	—·406
Dras	34	26	75	45	3,081	8·778	9·074	—·296
Srinagar	34	4	74	50	1,590	9·090	9·338	—·248

* Figures in these columns require a correction of —·016 to bring them into accord with the Survey of India determinations of gravity.

The observations, of deflection of the plumb line and of the force of gravity, were made at thirteen stations in the Himalayas and the Central Asian plateau. Only the figures directly derived from observation have been announced, so the deflections are not usable for the present purpose ; they suggest the existence of a belt of southerly residuals, to the south of the axis of maximum elevation of the surface, and northerly residuals to the north, but no dependence can be placed on this suggestion until the effect of topography and its compensation has been worked out in detail.

The gravity observations are similarly given as the observed values, accompanied only by the theoretical value, with the free air correction applied. In this case it is easy to compute the Bouguer correction for masses below the level of the station and this has been done ;[1] the figures are given in the tabular statement below. The values of the Bouguer anomaly for the stations printed below Leh and Lamayuru, indicate a general decrease in the defect of mass from the central stations outwards, towards the margin of the hills, which suggests that the application of the correction for compensation will result in positive anomalies at the outer stations and negative, or at least smaller positive, anomalies at the inner ones, but as no estimate, even approximate, of the amount of the correction can be made till it has been computed in detail, no use can be made of these stations. Moreover, all these stations are situated in the re-entrant angle, between the terminations of the Himalayan and Hindu Kush systems of ranges, where the physical conditions would be less simple than along the Himalayas proper. This objection does not apply to the stations at Dipsang and Leh, or, to a lesser extent, at Lamayuru. At the latter two stations the compensation correction is not likely to be materially different from that which has been computed for Moré, or about ·43 dyne, which is almost the same as the amount of the Bouguer anomaly ; consequently we may take it that the Hayford anomaly at these stations will not be large, whether positive or negative. At Dipsang the method, which gave a good approximation at Moré, is no longer applicable, it is probable that the allowance for compensation will be greater than at Moré or Leh, but improbable that it will equal the increase in defect indicated by the Bouguer anomaly, so that the resulting anomaly will probably be negative and may be large.

[1] Using the formula given by Capt. H. J. Couchman. *Surv. Ind. Prof. Paper* No. 15, p. 3, 1915.

However this may be, the observations clearly show that the large and increasingly large, positive anomalies, found at the Survey of India stations, near the outer edge of the hills, are not maintained, but disappear, in the central part of the range ; and beyond this it is not necessary to go.

From the foregoing particulars it will be seen that the fuller observations and computations now available, confirm the conclusions, drawn in the Memoir, from the approximate methods then alone available. These were that along the marginal portion of the mountains there was a zone of super-elevation where the underground defect of density, or compensation, corresponded to a lesser altitude than the actual height of the surface above sea-level; that this super elevation probably did not extend over the whole range, but disappeared towards the interior and might possibly be succeeded by a region where compensation was in excess, corresponding to a greater height of surface level than actually existed; that bordering the range, and following approximately the line of the alluvial deposits of the Punjab and Upper India, there was a belt of over-depression of the surface, where the compensation corresponded to a greater elevation of the surface level ; and that beyond this belt of over-depression there followed one of super elevation which traversed the Northern part of the Peninsular rock area and passed, on either hand, under the alluvium of the rivers of the Punjab, and of the Ganges and Brahmaputra. It was also pointed out that, so far as the two zones of super-elevation and over-depression, adjoining the outer boundary of the Range, are concerned, the phenomenon is what would be expected if the elevation of the hills were due to some form of direct uplift, and the outer crust of the earth, resting on more yielding material, possessed a degree of rigidity which prevented it from immediately and fully taking up the flexure, induced by the process which led to elevation in the one region and depression in the other.[1]

[1] In addition to the evidence quoted in the Memoir, of similar conditions existing in other mountain ranges, reference may be made to the detailed computation, by Mr. W. Bowie, of certain gravity stations in the Alps (*U. S. Coast and Geodetic Survey, Special Publication*, No. 40, 1917). According to these a group of five stations round and about Zermatt, in the southern and outermost range, gave anomalies ranging from +·044 to +·057, with a mean value of +·051 ; while five others, in the region of the Bernese Oberland, about 30 miles further into the range, gave anomalies ranging from —·010 to +·013 with a mean value of +·002.

Recently there has appeared the account of some observations which are instructive as an illustration of the processes involved in the explanation referred to above. It is well known that the working out of coal-seams underground leads to settlement of the surface, and, in a recent (Oct. 1922) discussion of this subject, at the Institution of Mining Engineers, Mr. Wallace Thorneycroft contributed some observations which had been made by him over a long series of years, according to which the long wall system of coal mining is accompanied by a surface wave of uplift over the still unworked coal in advance of the working face, and a depression in rear of it, where the coal has been worked out.[1] The cause of the latter is obvious, in the loss of support due to the removal of the coal-seam ; the former can only be attributed to a degree of rigidity of the rocks overlying the seam, which transmits part of the flexure, caused by loss of support behind, to the untouched rock, in advance of the working face, and so leads to a bending upwards at the surface of the ground. If this effect can be produced in the comparatively thin and weak layer of rock overlying a workable coal-seam, it is not unreasonable to suppose that a similar effect would take place where the much thicker, and certainly stronger rocks, of the earth s crust as a whole, are concerned.

These observations come opportunely as an illustration of part of the processes involved in the uplift of a great mountain range, as it has been developed in this investigation, which may be taken as a contribution to our knowledge of the mechanism, though not of the ultimate cause, of the origin of mountains and, indirectly, of the major relief of the outer surface of the solid earth.

[1] *Colliery Guardian*, 24th Nov. 1922, p. 1276.

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