Presidential Address.

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PROGRESS OF GEODESY IN INDIA.

I propose in this address to follow the suggestion made by our first President Sir Lewis Fermor at Indore last January that is to deal first briefly with the activities of our Institute during the past year and secondly to review the progress of the particular branch of science with which I am connected.

In reference to the National Institute, I wish first to mention the great loss that we have suffered in the retirement from service of our first President Sir Lewis Fermor. Speaking as one who has had the privilege of serving under his chairmanship on the Committee charged by the Indian Science Congress to bring this Institute into being, I can affirm without any hesitation whatever that our existence to-day is largely due to the tact, energy and judgment displayed by Sir Lewis Fermor during the whole of our proceedings.

In the name of the Council of the Institute and, I feel sure, of the whole body of Fellows I take this opportunity of thanking him for his work on our behalf.

The chief event of our Institute year has been the publication of the first part of Indian Science Abstracts. The work involved in the preparation of these abstracts is very great but it could be materially lessened if authors of scientific papers would assist by forwarding very short abstracts of them to the Institute. May I appeal for the co-operation of authors in this respect so that these abstracts may be fully worthy of this great country ?

Our other activities have been described briefly in the Annual Report and I will only refer here to the symposium held in Calcutta, at which and also at the General Meeting in Simla, many interesting papers on the productivity of the soil were read and discussed by the many experts present from all parts of India.

It is hoped that these symposia will continue to be a regular feature of the activities of our Institute.

We are deeply grateful to those who have made donations to the funds of our Institute during the year. But we are not yet self-supporting ; in 1936 nearly Rs. 6,000 has had to be spent from our capital and a similar deficit in income is expected next year. We must therefore depend on the continuance of such donations. May I appeal to the generosity of the Princes and people of India and to the Governments of India and of the Provinces to help this truly National Institute in its task of promoting and still more of co-ordinating the scientific activities of India ?

Speaking not as your President but as one who has spent over 30 years in India, I am convinced of the necessity, in this vast country, of a National Institute such as ours. Geographical difficulties there may be but there should not be financial ones and I look with confidence to those who have the power to remove them.

I now turn to the second part of this address—the Progress of Geodesy in India.

The study of Geodesy in India has been for many years confined almost entirely to the Survey of India department of the Government of India and as the head of that department, it appears to me to be a suitable subject with which I should deal. I must however explain that I have not personally been connected with this branch of our departmental activities for many years and I can therefore only be the somewhat halting mouthpiece of others.

Geodesy, or earth measurement, is a science with which any survey department is intimately concerned. Without knowledge of the shape, or as it is generally termed the figure, of the earth the mapping of any considerable portion of the earth's surface is impossible, in the sense that the positions of points on that surface cannot be accurately defined by their latitude and longitude, and isolated surveys cannot be connected together.

The making of disconnected maps in India began about the middle of the 18th century but it was not until the end of that century that a start was made to cover India with a network of accurately fixed triangulated points. This network was primarily required for the control of surveys by preventing the accumulation of errors, but it has been used along with triangulated arcs in other parts of the globe to determine the figure of the earth and to this extent its purpose was geodetic.

The year 1802, when Colonel William Lambton measured his first base line near Madras may be taken as the beginning of the study of geodesy in India. This study has continued with little interruption to the present time.

India has been a particularly favourable area for this study. Firstly, with the exception of the United States of America, it is probably the largest developed area under the control of one administration. The difficulties, met with in other continents, in the initiation and co-ordination by different Governments of geodetic work have consequently been absent. Secondly, its shape provides an extremely long stretch of land area on one meridian; from Cape Comorin in a due northerly direction to the foothills of the Himalaya (beyond which accurate geodetic work is hardly practicable) we have some 1,500 miles of country available. The value of this lies in the fact that prior to the electric telegraph the accuracy of astronomical determinations of longitude was in no way comparable to those of latitude. Consequently the earlier attempts to derive the figure of the earth were based on arcs measured along a meridian and have only comparatively recently been extended to arcs along a parallel. Thirdly, in the mountains to the north it possesses the most elevated portion of the earth in close proximity to deep oceans. It has at its very door ample material from which the attraction of local masses can be calculated and analysed, and theories formulated as to the structure of the earth. But it has been fortunate in another way. All these favourable attributes would have been wasted, anyhow for many years, but for the two great pioneers of geodesy in India, Colonel Lambton and Sir George Everest. These two between them controlled the early geodetic work in India for over 40 years and laid down for their successors a lasting framework on which to build.

The earliest years of geodetic study in India were spent in the measurement of base lines and arcs of triangulations and astronomical observations of latitude at selected stations along these arcs. By 1830 sufficient data had been accumulated to enable Sir George Everest to calculate his figure of the earth. The necessity for a recalculation of this figure had been apparent for some years but had obviously to wait until data were deemed to be sufficient. Until then the calculation of latitude and longitude of triangulated points, necessary for the purpose of survey, had to be based on some more or less arbitrary figure and it is known that this arbitrary figure had to be changed several times, as its unsuitability became apparent.

Everest's figure has been used for the computation of the whole of the Indian triangulation and it is therefore of interest to record that it is an oblate spheroid of which the major or equatorial semi-axis is 6377·3 kilometres with an ellipticity * or flattening of $\frac{1}{300{\cdot}8}$. Further investigations have shown that this spheroid is slightly too small, the modern value of the major semi-axis being about 6378·4 kilometres or some 1,200 yards greater, with an ellipticity in the region of 1/295 making the polar semi-axis about half a mile greater than Everest's.

The result of using Everest's spheroid as the reference figure for computing the elements of the Indian triangulation is that India occupies on its maps slightly more than its proper share of the earth's surface. In longitude from Baluchistan to Burma a distance of some 2,500 miles this excess is about 2,500 feet. This excess will cause no embarrassment until our neighbours carry out independent geodetic triangulation and mapping up to our common frontier where each point on the ground will then have two values of latitude and longitude, our own and our neighbours'. Until there is a prospect of this, the immense labour of republishing all Indian maps on a corrected graticule is not worth undertaking. Siam is at present our only neighbour that has carried out accurate triangulation up to the Indian border but as they have so far accepted the Indian values of latitude and longitude for their base station there is no discrepancy in maps.

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* If a = major semi-axis (equatorial)
b = minor semi-axis (polar)
then ellipticity $= \frac{a-b}{a}$.

DEFLECTION OF THE VERTICAL.

The geodetic method of calculating the figure of the earth is to relate the linear distances along a meridian or parallel between fixed points as determined by triangulation with the angular distance as determined by the difference of astronomical latitudes or longitudes. Such a method can only give good results if the instrument to measure the vertical angles necessary for latitude or time is truly horizontal, that is to say tangential to the spheroid of reference which is to be obtained. In the vicinity of large excesses of matter this condition is not obtained, since the mass deflects the vertical. All astronomical measures of latitude or time are therefore in error by the difference between the local vertical or direction of gravity, and the true vertical or normal to the spheroid of reference.

In calculating this spheroid therefore it is clear that stations in the vicinity of very large excesses or deficiencies of matter should be avoided.

With the elements of the spheroid of reference thus obtained the latitudes and longitudes of points fixed by triangulation are calculated and by comparing these values with those obtained astronomically a measure of the angular displacement or deflection of gravity is obtained. It must however be remembered that this measure is not absolute but will vary as the elements of the spheroid, or other figure of reference selected, are changed.

When these deflections were obtained at stations near the foot of the Himalaya and it was found, of course, that they were towards the mountains, attempts were made to connect the amount of deflection with the amount of the visible excess of matter. It was soon apparent that such connection presented great difficulties. The calculated effect of the visible excess of matter was in all cases far greater than the observed deflection. At Dehra Dun at the foot of the Himalaya, for example, the calculated deflection was 86 seconds of arc as against an observed value of 37 seconds.

The question was referred about 1853 by Sir Andrew Waugh, the Surveyor-General, to Archdeacon Pratt of Calcutta, a distinguished mathematician, and he propounded his theory of mountain compensation or what is termed isostasy to-day. I return to this theory later ; it is sufficient here to remark that the theory did not completely explain the observed deflections.

OTHER GEODETIC WORK.

For nearly forty years this aspect of geodesy was not seriously pursued in India no doubt because it was realized that more data was necessary, but in 1901 Sir Sidney Burrard again directed attention to the problem in his famous paper ' On the attraction of the Himalaya mountains upon the Plumb line '. During this interval geodetic work did not cease. India was gradually being covered with a network of primary triangulation, which is even to-day not quite complete, tidal observations were made to determine the mean sea level as a datum for the level net and the first series of pendulum observations to determine the force of gravity were carried out in the late 1860s. The telegraphic connection of India with Europe enabled an accurate calculation of longitude to be made about 1898, incidentally shifting India some 2½ miles west of its previous place on the globe to occupy a position which modern methods and apparatus have shown to be extremely accurate.

RECENT PROGRESS.

The present century has seen a great revival of geodetic study in India. The principal activity has been the accumulation of values of the force of gravity by means of the pendulum and of its direction by astronomical observations already referred to. In 1909 Mr. J. F. Hayford of the United States Coast and Geodetic Survey published his investigations into the theory of isostasy and this was shortly followed in India by preliminary discussions of the correctness of his theory as judged by Indian data.

Hayford's theory stated briefly was that above a certain depth below sea-level the mass in any column of unit area is the same whatever its height, or in other words that mountains and seas are compensated by underlying deficiencies and excesses of density. The theory is practically the same as that of Archdeacon Pratt to which I have referred above but is stated in a more precise way. Hayford's calculations of the depth at which compensation was complete produced the figure of about 70 miles, subsequently reduced to about 60 miles, below the sea-level surface.

Although this theory reduced materially the anomalies or differences between the theoretical and observed values of the force and direction of gravity, thus showing that a certain degree of compensation does exist, it has all along been held in India that the isostatic theory is only a partial explanation of observed results. It has been more successful in North America than in India in reducing anomalies and this may possibly indicate that, the former continent is geologically more stable. In India, however, the data accumulated seem clearly to point to the existence of deep-seated belts of excesses and deficiencies of density which have little relationship to surface geology or topography. The existence of what is probably the most marked of these belts was suggested by Sir Sidney Burrard some 30 years ago and called by him the Hidden Range, which runs across India slightly north of west through Jubbulpore. He derived this from a study of the deflections of the plumb line in Northern India and its existence becomes more and more certain as data are accumulated, not only of the direction but of the force of gravity. Such belts are inconsistent with any rigid and precise theory of isostasy such as that enunciated by Hayford which assumes that underlying densities vary only with surface heights and depths. Admittedly any theory as to the density of deep-seated masses must be put into a reasonably precise form to permit its effect on gravity to be computed with reasonable ease and one cannot condemn such a theory for its failure to explain all anomalies. The object should be to superimpose on the theory broad hypotheses which remove so much of the residual anomaly as to enable the remainder at any station to be attributed to such local variations of density as are acceptable to geologists. Clearly any anomaly of gravity at any one station can be removed by *some* assumption of local density but this assumption will affect neighbouring stations also and may increase the anomaly there; it may also be intrinsically impossible. Thus earlier attempts to explain by local conditions the great deficiencies of gravity in North Bihar resulted in the postulation of such a depth of light alluvium as could not be accepted.

If, however, broad assumptions of deep-seated variations of density do succeed in very materially reducing anomalies over large areas without increasing others, there is some certainty that they are correct. It is on these lines that Lt.-Colonel Glennie of the Survey of India and a Fellow of this Institute has been working for some years. After allowing for a measure of isostasy and for the effect of the Hidden Chain, he finds that the residual anomalies in the force of gravity can be further materially reduced by postulating other continuous crests and troughs in the dense sub-crust. He calls these up-warps and down-warps and has propounded theories as to their origin which are being discussed. Charts showing these warps are published in the Geodetic Reports of the Survey of India. The study of these deep-seated features, which are believed to originate some 10 to 20 miles below the surface, will, it is hoped, throw some light on seismological problems and also on so different a matter as water-logging in irrigated and other areas.

THE FORM OF THE GEOID.

Hitherto in referring to the figure or shape of the earth we have considered only a generalized figure which can be expressed in a reasonably simple mathematical form. Such a form is necessary for purposes of computation—to convert the measurements obtained by triangulation into latitude and longitude of the points fixed. By the middle of the eighteenth century it had become established that the actual shape of the sea-level surface of the earth, i.e. the geoid, could be more closely represented by a simple oblate spheroid than by a sphere. It is quite possible that an even closer approximation would be a tri-axial ellipsoid but this would involve considerable loss of computational ease.

All countries which have executed any triangulation use an oblate spheroidal figure for computation of latitude and longitude but the elements of these spheroids are not always the same. In India, as I have mentioned, the spheroid used could definitely be improved upon although the labour involved in the change would be immense. But the enormous advantages that India has derived from the early execution of triangulation has vastly outweighed the disadvantage of using Everest's spheroid and we have no cause to reproach our predecessors for this use. Had they postponed the computation of the triangulation until the elements of the spheroid had been more accurately determined the main advantage of that early start would have been lost. As it is, India has been free from the difficulties experienced by many countries which have carried out detached surveys without a rigid framework of triangulation. Our difficulties in fact have been relegated to the frontiers where they are clearly of less importance.

But whatever spheroid is used it is evident that it cannot absolutely represent the geoid. Excesses and deficiencies of matter and of density must distort the geoid from any purely mathematical form, and it is to these distortions, or as they are usually called separations, of the geoid from the assumed spheroid that considerable attention has been recently devoted in India.

From a study of the changes in the direction of gravity along a line of stations, it is possible to compute the changes in separation that will account for them. Given a sufficiency of such stations the separations can be displayed by contours on the spheroid thus clearly showing the shape of the actual geoid.

Charts showing these contours are published from time to time in the Geodetic Reports of the Survey of India and the shape of the geoid in Peninsular India appears now to be fairly well established. More data are needed in Burma and in the Himalaya in both of which areas the geoid seems to present unusual features. Whereas in Peninsular India the separation of the geoid from the International Spheroid, the figure adopted by the International Union of Geodesy and Geophysics, varies between about 35 feet above to 40 feet below, there are indications that in Southern Burma the geoid rises to something like 140 feet above the spheroid.

In spite of the forthcoming separation of Burma from India it is hoped that it may be possible to obtain further data in this area to elucidate this peculiar feature.

The Hidden Range is clearly shown by these geoidal contours which along a line through Sambalpur, Jubbulpore, Jodhpore, and Quetta indicate a crest of between 20 and 35 feet as compared with depressions of 40 feet near Gorakhpur to the north and 10 feet near Belgaum and Madras to the south.

These geoidal contours have an intimate bearing on the heights of mountain peaks ; these have been obtained by measurements of angles of elevations from distant points, and not, of course, by spirit levelling up to the summit. While the latter method gives true geoidal heights, since the levelling instrument at each station assumes a position parallel to the geoid, the former does not. After correcting for refraction the height obtained is above the geoid at the station of observation and would only represent the true geoidal height if both station and peak were on the same geoidal contour. As this is unlikely, the heights of all distant peaks require a correction at present unknown and this fact explains the reluctance of the Survey of India to change the well-known height of Mount Everest, 29,002 feet, to a more accurately calculated but non-geoidal value of 29,141.

If I may be permitted a word of departmental glorification, I will conclude by remarking that the geodetic activities of the Survey of India have been commended on many occasions by other countries and it is our hope that these activities will be continued for many years to come.

The study of geodesy is inevitably one involving much patience and persistence ; results are hard to come by and their practical value is often doubted. Provided liaison is maintained with geology and geophysics, geodesy must lead to a better knowledge of the earth's structure and thus extend the discoveries of these sciences.