

## THE DEFLECTION OF THE PLUMB-LINE IN INDIA.\*

By E. A. REEVES.

THE question of the deflection of the plumb-line from its true vertical position, owing to the unequal effect of gravity occasioned by irregularities in the formation of the Earth's crust, is one that calls for most serious consideration whenever a complete trigonometrical survey of a country is undertaken. Such irregularities cause errors in the astronomically determined positions, inasmuch as they affect the levels of the theodolite with which the observations are taken. Even in comparatively flat countries, such as Russia, this is a subject which cannot be ignored, and near Moscow, on a line 60 miles long, running nearly east and west over a plain, northerly deflections of 8" are found, while along a parallel line 9 miles to the south the plumb-line hangs vertical. Along a third line, 9 miles further to the south, there is a southerly deflection of 8". This is doubtless an exceptional case, and there are probably few places on the Earth's surface with so great a change in the direction of the plumb-line in so short a distance. Yet, as might be expected, in India, with the massive range of the Himalayas stretching across its long northern frontier, the question is by no means insignificant, and in very early days of the Indian trigonometrical survey it was recognized that it would have to be carefully considered. It was found, for instance, that the latitudes of places resulting from observations taken with the best instruments and computed with the utmost care, would not coincide exactly with the results obtained by triangulation. Similar differences were also noticed in the longitudes and azimuths. Although these differences nowhere amounted to more than a few seconds, it soon became evident that they were not accidental, nor due to errors of computation, and could only be attributed to the deflection of the plumb-line due to inequalities in the attraction of gravity. Naturally, the great mass of the Himalayan range was turned to as the principal cause of these abnormal conditions, and in the earlier days of the Survey of India a good deal was written upon the subject with a view to its fuller investigation. Elaborate computations were, amongst others, undertaken in 1852 by the late Archdeacon Pratt, of Calcutta, at the request of Sir Andrew Vaugh, the then Surveyor-General of India, the results of which were afterwards given in the *Philosophical Transactions of the Royal Society*. As a consequence of these investigations it was pretty generally accepted that the effect of the Himalayas on the direction of the plumb-line in India was compensated by the deficiency of matter beneath that range, or some other cause, and it has for the last forty years or so been considered impossible that the range can exert any influence upon the direction of the plumb-line so far south as Central India; thus it was supposed that all observed discrepancies between the astronomical and geodetic positions of places at any considerable distance from the Himalayas were due to local inequalities. The principal reason for believing that the attraction of the Himalayas was counteracted by an invisible cause was the fact that the observed effect of the attraction of the Himalayas on the plumb-line at Kaliána (in lat.  $29^{\circ} 30' 48''$ ), the northern terminus of the Indian Arc, is  $5''\cdot236$ ; whilst the attraction of the apparent or

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\* 'The Attraction of the Himalaya Mountains upon the Plumb-line in India.' Considerations of Recent Data by Major S. G. Burrard, R.E., Superintendent Trigonometrical Surveys. Published by direction of Colonel St. G. C. Gore, R.E., Surveyor-General of India. Professional Paper No. 5. Dehra Dun: printed at the Office of the Trigonometrical Branch, Survey of India. 1901.

superincumbent mass of the Himalayas at that point is sufficient to produce a deflection of  $27''\cdot853$ , according to the calculations of Archdeacon Pratt. But, as will be seen later on, Major Burrard, in the report now under consideration, clearly shows that, owing to our more perfect knowledge of the vast mountain systems of Northern India, and a more complete acquaintance with the depths of the Indian ocean, together with other reasons, it is necessary that the argument should be reconsidered, and the computations made over again; and when this is done, he comes to the conclusion that there is no reason to suppose that the effect of the Himalayas upon the direction of the plumb-line does not extend to Southern India, and even at Cape Comorin the range may cause a deflection of one or two seconds.

The question of the deflection of the plumb-line in India is surrounded with many difficulties and obscured by apparent inconsistencies; nor does Major Burrard profess to have finally cleared up the matter, although his work is most important as being a re-investigation of the subject, based upon the most recent data. Before a thoroughly satisfactory conclusion can be arrived at, many more observations must be taken and additional information obtained; but, as Major Burrard states in his preface, "a periodical investigation is essential, if we wish to design the most profitable programmes of future work." For many years the subject may be considered to have been in abeyance, except for the ever-accumulating evidence necessarily resulting from the progress of the Indian Trigonometrical Survey, and it was only seriously revived by the paper read by the late General J. T. Walker (Surveyor-General of India) before the Royal Society in 1895. Before it is possible to ascertain how much the Himalayas deflect the plumb-line throughout India, it is, of course, necessary to clear each observation station from the effect of *local* attraction, and in order to do this, General Walker in his paper proposed the "group" system, i.e. that each station should be surrounded by other stations at short distances from it, and that observations should be taken at all of these, from which the amount of *local* attraction could be ascertained. In the same paper he attempts to explain the preponderance of northerly deflections throughout India, by assuming that local attraction is producing a *southerly* deflection at Kaliánpur, the station of reference of the Indian Survey.

This paper brought the question again into prominence, and it was decided by the Survey of India to carry out General Walker's suggestions, and establish a "group" of observation stations around Kaliánpur, in order to determine the local attraction at that place.

The result of the observations taken at these stations is given in Major Burrard's report, on page 7 of which appear the three following values of the latitude of Kaliánpur:—

Value adopted in computations of the triangulation	...	...	24	7	11	26
Mean observed value of six different observations taken at Kaliánpur itself, by different observers between 1824 and 1899 (the greatest difference between them being $0''\cdot85$ )	...	...	24	7	10	97
Value derived from the group	...	...	24	7	11	57

On the assumption that the last of the three, the value derived from the group is freed from the effect of local attraction, it is deduced that the astronomical zenith at Kaliánpur is displaced  $0''\cdot60$  to the south, and that there is a deflection of the plumb-line in the meridian at Kaliánpur of  $0''\cdot60$  to the *north*. This result was quite unexpected and surprising, for instead of the local deflection being southerly at Kaliánpur, as General Walker had predicted, it was thus found to be *northerly*. After this the whole subject was reopened; observations were extended, fresh computations made from the latest information, old theories and conclusions

reconsidered, the account of all of which Major Burrard gives in his report, which represents a vast amount of most painstaking work.

This report consists altogether of one hundred and thirty pages of letterpress, in addition to numerous charts and diagrams, and is divided into seven sections, as follows: I. On the errors of the initial values of latitude and azimuth in India. II. The deflections at Kaliánpur calculated from the configuration of the ground in the vicinity. III. The Pendulum Observations at Kaliánpur. IV. (a) The influence of the Himalaya mountains and of the Indian ocean on the plumb-line in India; (b) the disturbance of the sea-level; (c) geological considerations. V. Comparison of calculated with observed values of deflections in the meridian. VI. Comparison of calculated with observed values of deflections in the prime vertical. VII. It is inferred that a hidden cause in Central India is masking true Himalayan effects. These are the headings of the principal sections of the work, and from them some idea may be obtained as to its scope and arrangement, which, as might be expected, is clear and satisfactory. In addition to these chapters there are two appendices, one giving a description of the stations of the Kaliánpur group, and the other the results of the azimuths observed in India and Burma. A useful epitome of the work is also given at the commencement.

There are altogether fourteen charts and diagrams, which serve well to illustrate the text, besides numerous pages of tabular matter. Some of the diagrams are very ingeniously arranged, and convey at a glance a great deal of information. Among the more interesting of these are those showing the local attractions in the meridian, and in the prime vertical at the stations of the Kaliánpur group, and the outline charts of India illustrating the positive and negative areas of (O-C) in latitude and azimuth. Positive areas are tinted red, and negative left white. Throughout the work "O" is taken as the astronomically observed latitude or azimuth, and "C" that computed from the triangulation. In the case of latitudes, if the plumb-line at any station is attracted to the north, the zenith will be displaced to the south, the observed latitude or O will be too small, and (O-C) is then a negative. As regards azimuths, if the plumb-line at any station is attracted to the east, the zenith will be displaced to the west, the observed azimuths or O, measured from south by west, will be too small, and (O-C) is again negative. When the opposite is the case, O-C is considered positive. It would have been interesting if specimens of the actual computation of the astronomical positions had been given, as well as a description of the instruments used, and the methods employed for eliminating the effects of refraction, which must be a matter of special importance when the whole argument sometimes depends on a second or two of arc, or indeed, as it is at times, the fraction of a second. As a frontispiece is given a cross-section of the outer Himalayan ranges on the meridian of  $77^{\circ} 25'$ , constructed from the contoured maps of the Indian Survey by Colonel St. G. C. Gore, R.E., Surveyor-General of India.

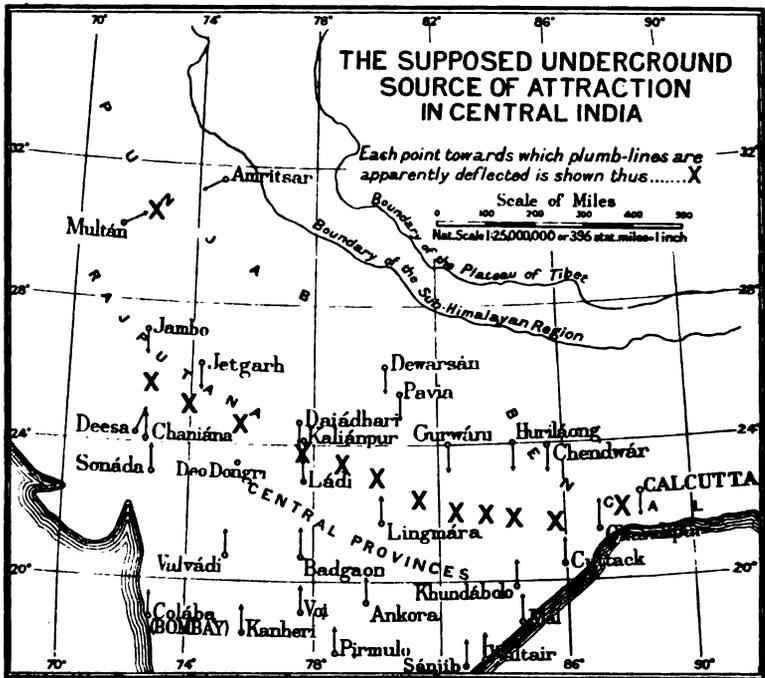
In his preface Major Burrard acknowledges the great assistance he has received from Mr. C. H. McA'Fee, Extra Deputy Superintendent, who has taken charge of the publication of his work; from Mr. C. L. Griesbach, C.I.E., Director of the Geological Survey of India, who has supplied him with valuable geological information, and several others. He also states that "a sense of loyalty to General Walker renders criticism of his theories an unwelcome task:" "and that such criticism can only be based on data that were never at his disposal, and that have been accumulated since his death." Many of the formulæ used in the computations are those arranged by Colonel A. R. Clarke, C.B., R.E., F.R.S., and given in his well-known work on geodesy.

It may be well now to state the principal conclusions which Major Burrard

considers these investigations point to, although he is evidently prepared to admit that further information may lead to their modification. He sums them up himself in the following words:—

1. "It is now believed that the coincidence of the change of sign of the deflections with the parallel of the station of origin is accidental, and possesses no significance." (It was previously considered an important and suggestive fact that at lat.  $24^{\circ}$  N., the latitude of Kaliánpur, the station of origin or reference, the sign of the deflection changed from north to south.)

2. "The change of sign in the deflections along the parallel of  $24^{\circ}$  is attributed to a great underground chain of excessive density stretching across India from east to west for over 1000 miles, the effects of its attraction being visible from lat.  $16^{\circ}$  to lat.  $30^{\circ}$ ." (Chart No. 12 of the report, which is here reproduced, shows this supposed underground source of attraction.)



3. "This chain is the probable cause of the positive deflections north of lat.  $24^{\circ}$ , and of the negative deflections south."

4. "It marks the true effects of Himalayan attraction: Himalayan effects thus suffer from both compensation and obscuration."

5. "The longitude arcs of the Punjab lead to the belief that the underground chain tends to the north-west in Rajputana, and maintains a parallelism with the Himalayas."

6. "The effects of the chain are superimposed on those of a far-reaching Himalayan attraction, the latter perhaps deflecting the plumb-line at Cape Cormorin through one or two seconds of arc."

7. "South of the chain, from lat.  $20^{\circ}$  to lat.  $8^{\circ}$ , the northerly deflection of the plumb-line has been observed to decrease gradually for 800 miles, the total decrease amounting to  $10''$  from  $-8''$  in lat.  $20^{\circ}$  to  $+2''$  in lat.  $8^{\circ}$ ; this decrease is possibly a Himalayan effect."