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PROFESSIONAL PAPER—No. 13.

INVESTIGATION OF THE THEORY

OF

ISOSTASY IN INDIA

BY

MAJOR H. L. CROSTHWAIT, R.E.,

DY. SUPERINTENDENT, SURVEY OF INDIA.

PUBLISHED BY ORDER OF THE GOVERNMENT OF INDIA.

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PREFACE.

No originality is claimed for this work. It is merely an attempt to apply Mr. Hayford's method to India. In this paper his words are often used, though sometimes not shown in italics.

In carrying out this long, and somewhat monotonous undertaking, I have had the willing assistance of Mr. Waller-Senior, Survey of India.

SIMLA:
April 1912.

H. L. C.

Investigation of the Theory

of

Isostasy in India

by

Major H. L. Crosthwait, R.E.,

Dy. Superintendent, Survey of India.

Explanation of Methods.

1. The object of this investigation was to ascertain, whether, making certain necessary assumptions, the condition called isostasy* exists in India.

2. The method followed was that adopted in a similar investigation carried out for the United States of America by Mr. John F. Hayford, of the United States Coast and Geodetic Survey.

Mr. Hayford has displayed considerable ingenuity in adapting the formula so as to reduce the labour of computation to a minimum. Without some such device the time and labour involved would make the work practically impossible.

3. The data already available, for India, consisted of the geodetic and astronomical latitudes of the stations under investigation; from which the quantity (A—G), or the astronomical *minus* the geodetic latitude for each station has been derived. (A—G) is the angle at the station between the direction of gravity and the normal to Everest's spheroid which has been adopted for India; it has also been applied to the Bessel-Clarke spheroid as explained on page 3 para. 14 and footnote page 4.

This quantity has a *plus* sign where the zenith of the station, as defined by a line normal to the adopted spheroid, is north of the zenith defined by a line normal to Everest's or Bessel-Clarke spheroid, and *minus* when the zenith is to the south.

4. The following is a short account of the method† adopted in computing the orographical deflection at stations. By orographical or topographical deflection is meant the theoretical deflection which should be produced by an irregular distribution of masses, if such distribution were to follow the irregularities of topography. The formula used is that due to Colonel A. R. Clarke, R.E., F.R.S., given in his work on Geodesy.

$$D = 12''{\cdot}44 \frac{\delta}{\Delta} h \left(\sin a^1 - \sin a_1\right) \log_e \frac{r^1}{r_1}$$

* Isostasy may be described as follows:—"The excess of material represented by that portion of the continent which "is above sea-level, will be compensated for by a defect of density in the underlying material The continents will be "floated, so to speak, because they are composed of relatively light material; and, similarly, the floor of the ocean will be "depressed, because it is composed of unusually dense material. This particular condition of approximate equilibrium, has "been given the name isostasy."

† For a detailed account the reader is referred to "The Figure of the Earth and Isostasy from measurements in the United States" by John F. Hayford, Washington 1909.

D is the deflection produced at the station by a mass of surface material of the earth, which is a stratum h miles thick, embraced by a four-sided compartment limited by two radial lines from the station, and by arcs of two circles with the station as a common centre, the circles having radii of r^1 and r_1; a^1 and a_1 are the angles between the radial lines and the meridian; δ the mean surface density of the earth, assumed to be $2 \cdot 67$; Δ the mean density of the whole earth taken as equal to $5 \cdot 576$.* The constant $12'' \cdot 44$ depends on the supposition that the earth may be considered a sphere of 3960 miles radius.

5. "The whole of the attracting stratum is assumed to be in the horizon of the station". "If the stratum considered within any compartment be that which is limited below at sea-level "and above at the actual irregular surface of the earth, then with considerable accuracy the "following statement based on the formula may be made:—For compartments bounded by circles "whose radii are in geometrical progression, the deflection produced at a station at the centre of "the circles in a direction parallel to the reference line, is for such compartment, proportional to "the mean elevation of the land surface within the compartment."

6. As exceptions to the above general statement the following cases require special treatment:

(*a*) Compartments so far from the station that the curvature of the earth must be considered, a correction has been introduced to meet this, as will be shown later.

(*b*) Compartments of which some part lies far above or far below the mean elevation of the compartment.

(*c*) Compartments near the station the mean surfaces of which lie far above or below the station, to these a slope correction has to be applied for which tables are provided.

7. In order to make the computation as simple and rapid as possible the following values were adopted:

$$\frac{r^1}{r_1} = 1 \cdot 426, \quad \sin a^1 - \sin a = 0 \cdot 25.$$

Substituting these and ratio $\frac{2 \cdot 67}{5 \cdot 576} = \frac{1}{2 \cdot 09}$ for $\frac{\delta}{\Delta}$ in the formula given in para 4 and expressing the height of the compartment above mean sea-level in feet instead of miles, we get

$$D = 12'' \cdot 44 \left(\frac{1}{2 \cdot 09}\right) \frac{h}{5280} (0 \cdot 25) \log_e 1 \cdot 426 = 0'' \cdot 0001000 \ (h \text{ in feet}).$$

From this it follows that every hundred feet of stratum above mean sea-level, in any compartment, produces a deflection of $0'' \cdot 01$ at the station.

8. Table I page 6 shows the rings with the outer radii of each set of compartments. The outer radius of ring 23 was arbitrarily made equal to unity.

9. In the case of compartments which fall in the sea, the depth of the ocean in feet was multiplied by 0.615† and the result treated as if it were a negative land elevation. For compartments which are partly ocean and partly land, the fraction of each was estimated and treated accordingly, care being taken to apply the correct sign to each portion.

* For the values of δ and Δ see "The Solar Parallax and its Related constants" by W. Harkness, Washington 1891.

† This quantity is derived as follows:—The ratio of the density of sea water to the average density of the crust has been taken as $\frac{1 \cdot 027}{2 \cdot 67} = 0 \cdot 385$. The surface of the ocean would, therefore, if the water were compressed to the density of the crust, lie $(1 \cdot 000 - 0 \cdot 385) = 0 \cdot 615$ multiplied by the depth below the present surface.

10. The outer radii of rings 1 to 6, if computed in the same manner as the other rings, would be 2456, 1722, 1207, 847·1, 594·0 and 416·6 miles, respectively. But for these rings it was necessary to introduce the correction for curvature mentioned in para 6(*a*) which gave the radii the greater value shown in Table I page 6.

11. The next step in the process is the construction of the templates on which are drawn the compartments, on the scale of the maps used, according to the conditions outlined in the foregoing paras. For this purpose sheets of transparent celluloid about 20″ × 20″ were used, each template comprising one quadrant only. When applied to the map with its centre on the station, and compartment No. 1 with its northern edge along the prime-vertical, it was possible to see the area indicated by the boundaries of the compartments, and from the contours, or heights, to estimate the average elevation.

12. Heights so read off were entered on forms, specimens of which are shown in Tables III and IV. Every hundred feet of height was entered in its proper place as 0·01 second. Thus a compartment having an average height of 800 feet figured as 0″·08 in the form.

13. It will be noticed that each ring contains 16 compartments, 8 of which lie to the south and 8 to the north of the station. According to the convention used, in the northern compartments all elevations above sea-level produce negative and those below sea-level positive deflections, while the opposite is the case in the southern compartments. The deflections produced by all the compartments in each ring are summed algebraically and entered, with their proper sign, in the column headed Horizontal sum. The figures in this column are the deflections that the topography would produce if there were no isostatic compensation. Mr. Hayford shows that in order to convert these deflections into those produced by an isostatically compensated topography, all that is necessary is to multiply the total for each zone, or ring, by a factor depending on its limiting radii and independent of its mean height.

These factors vary according to the depth at which it is supposed that isostatic compensation is complete. In this investigation the depth which Mr. Hayford found to be the most probable for the U. S. of America, namely 113·7 Km., has been adopted. The meaning of this is that while the density of the crust varies according to surface irregularities above a depth of 113·7 Km. below that depth density increases uniformly and is independent of surface conditions. The factors for a depth of 113·7 Kilometres computed by Mr. Hayford (*vide The Figure of the Earth and Isostasy*, p. 70) are given in Table II page 7.

An example of their application in the case of Kalianpur is given in full, *see* Table III page 7.

14. The topographic deflections in the meridian were computed for 102 latitude stations and in the prime vertical for 18 longitude stations.

On pages 9 to 14 will be found the results. The stations have been arranged according to regions in the same manner as they are grouped in the Great Trigonometrical Survey of India Vol. XVIII, Astronomical Observations for Latitude, pages (531) to (542).

In column 3 is shown the topographic deflection due to the visible surface masses. Column 4 shows the deflection, uniform isostatic compensation considered, the assumed depth being 113·7 Kilometres. This is obtained by applying the factors given in Table II to the topographic deflection for each ring. The values of (A – G) have been obtained by deducting the geodetic values of latitude from the astronomical values. For the values of (A – G) in col. 5 the geodetic latitudes have been computed on the assumption that the direction of gravity at Kalianpur is vertical, and they have been based on the obsolete spheroid of Everest (G.T.S. Vol. XVIII). For the values of (A – G) col. 6 the geodetic latitudes have been computed on the assumption, that the direction of gravity is deflected 4″ south at Kalianpur, and they have been based on the Bessel-Clarke spheroid* :— Equatorial radius 6,378,190 metres, ellipticity $\frac{1}{299 \cdot 15}$.

Column 7 shows the difference between column 6 and column 4, that is the difference between the value of the actual and the computed deflection, or the unexplained residual.

These residuals, for each station, have been plotted on the accompanying chart.

15. On page 14 are exhibited the results of treating longitude stations for deflection in the prime vertical. Column 4 is the topographic deflection obtained by turning the template through 90° (*see* example, Table IV) as compared with the latitude position. Column 5 is the deflection, isostatic compensation considered. In columns 6 and 7 are given the values of (A—G) cos λ applied to the Everest spheroid and to the Bessel-Clarke spheroid, *see* para 14 and footnote. Column 8 is the difference between columns 7 and 5 and is the unexplained residual.

As regards signs, the convention used is that a westerly deflection has + sign, while a — sign means a deflection of the plumb-line to the east.

Note on Residuals.

What are here called the residuals are the differences between the deflections computed on the hypothesis of uniform isostatic compensation an' the observed deflections A—G, applied to the Bessel-Clarke spheriod. They are given for each station in col. 7 of the tables of results. As in U. S. A., the stations of India have been divided into groups, or regions, following those (for India) given in Vol. XVIII.

With a view to comparing results obtained in the two countries the following tables have been prepared showing the mean residual for each group, or region :—

U. S. A.

				″
Group	S. E.	mean residual	...	—0·74
,,	N. E.	,,	..	—1·04
,,	Central	,,	...	—1·66
,,	W.	,,	...	—4·02

India.

						″
Region No.	1	Himalaya Mountains	mean residual	...	—	16
,,	2	Plains at the foot of Himalaya Mountains	,,	...	—	2
,,	3	N. E.	,,	...	+	8
,,	4	Central	,,	...	+	5
,,	5	N. W.	,,	...	+	4
,,	7	W.	,,	...	—	3
,,	8	E.	,,	...	—	2
,,	9	S.	,,	...	+	1

Speaking generally it would appear that isostatic conditions are much more nearly realized in America than in India, *i.e.*, if we are to take the smallness of the residuals as an indication of the completeness of isostatic compensation. In India we have an example of a continent where very large natural convulsions have taken place, in recent geological times, producing upheavals

* For Bessel-Clarke spheroid, for zero of verticality in India, and for most probable deflection at Kalianpur *see* Phil. Transactions, Royal Society A. Vol. 205, 1905 and Professional Paper No. 12 Survey of India, *On the Origin of the Himalaya Mountains*, by Colonel S. G. Burrard, C.S.I., R.E., F.R.S., 1912.

of the crust on a scale quite unknown in any other part of the globe. In U. S. A. disturbances have been comparatively slight. Taking these facts into consideration, and granting that there is always a tendency towards isostatic equilibrium, is it not reasonable to suppose that while the attainment of equilibrium is already far advanced in America, in India it is still in an immature state, and compensation is by no means so perfect? The earth's crust in India is in a process of settling down and may be, comparatively speaking, in a state of strain.

It should be noted that the residuals are derived from quantities which result from a certain set of assumptions, namely the ratio of the densities at 1/2·09, and a depth of compensation of 113·7 kiloms.

The assumed density of 5·576 for the whole earth probably rests on a surer basis than 2·67 for the surface density, which is not easy to determine, and probably varies considerably.

It has been assumed that the distribution of density is uniform. Assuming the doctrine of isostasy to hold, is it not possible that in any two columns of matter extending from the surface down to the depth of compensation, there may be the same mass, and yet that the density may be very differently distributed in the two columns? These two columns, though in isostatic equilibrium, would act differently on the plumb-line owing to the unequal distribution of mass.

The draw-back to treating this subject by hard and fast mathematical formulæ is that we are introducing into a discussion of the constitution of the earth's crust a uniform method when, in reality, probably no uniformity exists. With these concluding remarks the results are here presented and left for future discussion.

Note on maps employed.

One-inch old Standard Sheets.—These maps are generally speaking old and out of date. They are not contoured and some of them exhibit very few heights. They were used in some cases from ring 25, or 0·49 mile, up to ring 15, or 17·1 miles. In many instances the ground round the stations is so flat that the inner rings produce no deflection. Maps, on this scale, are not available for southern India.

Atlas Sheets of India, scale 1 inch to four miles.—These are available for almost all stations. They were used from ring 15 to ring 11, or to radius 70·7 miles. They are also mostly very old and not up to modern requirements. They are not contoured and some of the sheets have no heights on them at all. They, generally speaking, extend up to, and include, the first snowy range of the Himalaya. In dealing with Himalayan compartments considerable difficulty was encountered. In many of them no heights whatever are shown. In these cases the estimation of compartment heights resolved itself, more or less, into guess work. In other compartments the heights which are given represent the tops of hills only. None are shown in the valleys. The absence of heights in the valleys, the sides of which are generally very steep, makes it extremely difficult to estimate the average elevation, and probably produces a tendency to give too high a value thereto. Defective as these maps are they were the most reliable available for India generally. Had they been contoured it would have added greatly to their value for this, and other purposes.

Contoured maps of India on scales of 1 inch to 32 miles, and 1 inch to 64 miles.—These maps were used when the distance became too great for the Atlas Sheets. They are old and contours are approximate only.

Stanford's Orographical Map of Asia, scale 1 inch to 137·6 miles.—This map was used beyond the limits of India up to the extreme radius of 2564 miles. It includes countries where data are very meagre, such as Arabia and parts of Central Asia. The information regarding these regions must very often be in error. But the compartments in these outer rings are at a considerable distance from the station, and when the factor for compensation (*see* table II) is applied to them a very considerable error can exist without producing any perceptible effect on the final result. At considerable distances from stations the projection of the map produces a displacement of the compartment in azimuth that could not have been corrected without the expenditure of an amount of labour, which, owing to the smallness of the compensation factors, above referred to, it was not considered necessary to undertake. However, the data available are so uncertain as to make the introduction of a correction for projection of doubtful value.

Map on a scale of 1 inch to 192 miles.—On this map were plotted all oceanic depths which could be obtained from available marine charts. Depths in fathoms were converted into feet, and the map was contoured. From these the average depths of compartments were estimated, the results being treated as described in para 9.

Speaking generally the maps available for this investigation were defective for the purpose for which they were required. Those which affect the results most are the one-inch and the quarter-inch maps, because the compartments falling in them, being nearest to the station, have the largest factors. As already noted these maps are not contoured, and in many cases heights are deficient.

TABLE I. RADII OF RINGS BOUNDING COMPARTMENTS.

Ring	Outer radius		Ring	Outer radius	
	Miles	*Kilometres*		*Miles*	*Kilometres*
1	2 564	4 126	20	2·899	4·665
2	1 757	2 828	21	2·033	3·272
3	1 219	1 962	22	1·426	2·295
4	850·8	1 369	23	1·0000	1·609
5	595·2	957·9	24	·7013	1·129
6	416·8	670·8	25	·4918	·7915
7	292·2	470·3	26	·3449	·5551
8	204·9	329·8	27	·2419	·3893
9	143·7	231·3	28	·1696	·2729
10	100·77	162·27	29	·1190	·1915
11	70·67	113·73	30	·0834	·1342
12	49·56	79·76	31	·0585	·0941
13	34·75	55·92	32	·0410	·0660
14	24·37	39·22	33	·0288	·0463
15	17·09	27·50	34	·0202	·0325
16	11·987	19·29	35	·0142	·0228
17	8·406	13·53	36	·0099	·0160
18	5·895	9·487	37	·0070	·0112
19	4·134	6·653	38	·0049	·0079

TABLE II. FACTORS (F) UNIFORM ISOSTATIC COMPENSATION CONSIDERED.

Ring	Factor	Ring	Factor
25	0·995	12	0·493
24	0·992	11	0·358
23	0·988	10	0·234
22	0·983	9	0·139
21	0·976	8	0·077
20	0·965	7	0·040
19	0·951	6	0·020
18	0·930	5	0·010
17	0·900	4	0·005
16	0·859	3	0·003
15	0·801	2	0·001
14	0·721	1	0·001
13	0·618		

TABLE III. COMPUTATION FOR LATITUDE STATION KALIANPUR.

Latitude Station No. 42.—Kalianpur, Latitude 24° 7′ and Height above M. S. L. 1765 feet.

Ring	No. of Sector																Hor. Sum	Continuous Sum	F.	F × Hor. Sum
	South Roman + Italic −								North Roman − Italic +											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
30																				
29																				
28																				
27																				
26																				
25								·17	·17								0·00		·995	
24								·17	·17								0·00		·992	
23								·17	·17								0·00		·988	
22								·17	·17								0·00		·983	
21	·17	·17	·17	·17	·16	·16	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	−0·02	− 0·02	·976	−0·02
20	·17	·17	·17	·17	·16	·16	·16	·17	·17	·17	·17	·17	·17	·17	·16	·17	−0·02	− 0·04	·965	−0·02
19	·16	·16	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·16	−0·01	− 0·05	·951	−0·01
18	·15	·15	·17	·16	·17	·17	·17	·17	·17	·17	·17	·17	·17	·16	·15	·15	0·00	− 0·05	·930	0·00
17	·15	·16	·16	·17	·17	·16	·17	·17	·17	·17	·17	·17	·17	·16	·15	·14	+0·01	− 0·04	·900	+0·01
16	·15	·16	·17	·17	·17	·17	·16	·17	·17	·17	·17	·17	·17	·16	·14	·14	+0·03	− 0·01	·859	+0·03
15	·14	·15	·16	·17	·16	·16	·17	·17	·17	·16	·17	·17	·16	·16	·16	·14	−0·01	− 0·02	·801	−0·01
14	·13	·14	·14	·14	·15	·16	·17	·17	·17	·17	·16	·17	·16	·16	·16	·14	−0·09	− 0·11	·721	−0·06
13	·15	·13	·13	·14	·14	·17	·17	·16	·16	·17	·16	·17	·16	·14	·15	·13	−0·05	− 0·16	·618	−0·03
12	·16	·16	·14	·16	·16	·16	·16	·15	·15	·17	·17	·15	·16	·15	·14	·13	+0·03	− 0·13	·493	+0·01
11	·18	·19	·18	·19	·17	·17	·15	·14	·14	·13	·16	·15	·15	·15	·13	·14	+0·22	+ 0·09	·358	+0·08
10	·17	·14	·13	·12	·15	·16	·16	·15	·11	·12	·13	·13	·10	·09	·09	·12	+0·29	+ 0·38	·234	+0·07
9	·16	·17	·24	·20	·15	·09	·15	·16	·11	·09	·11	·11	·07	·07	·08	·11	+0·57	+ 0·95	·139	+0·08
8	·16	·19	·19	·20	·20	·14	·10	·16	·12	·09	·09	·08	·05	·05	·05	·06	+0·75	+ 1·70	·077	+0·06
7	·19	·09	·09	·12	·14	·13	·09	·09	·16	·13	·14	·07	·06	·05	·04	·06	+0·23	+ 1·93	·040	+0·01
6	·15	·14	·09	·10	·12	·15	·18	·01	·08	·09	·07	·07	·08	·11	·11	·02	+0·31	+ 2·24	·020	+0·01
5	·16	·17	·09	·16	·14	·18	·06	·00	·04	·04	·07	·37	1·35	1·55	1·55	·10	−4·11	− 1·87	·010	−0·04
4	*·22*	*·37*	*·49*	·15	·22	·03	*·43*	*·70*	·17	·23	·40	1·25	1·60	1·50	1·50	·60	−9·06	−10 93	·005	−0·05
3	*·31*	*·61*	*·67*	·00	*·12*	*·43*	*·80*	*·49*	·20	·45	·50	·60	·50	1·00	1·50	·80	−8·98	−19·91	·003	−0·03
2	·00	*·61*	*·80*	*·86*	*·55*	*·67*	*·86*	*·46*	·18	·00	·04	·09	·05	·20	·60	·47	−6·44	−26·35	·001	−0·01
1	·01	*·49*	*·98*	*·92*	*·61*	*·80*	*·80*	*·43*	·09	·20	·05	·03	·06	·30	·25	·02	−6·02	−32·37	·001	−0·01
																				+0·07

TABLE IV. COMPUTATION FOR LONGITUDE STATION KALIANPUR.

Longitude Station No. 42.—Kalianpur, Latitude 24° 7′, Longitude 77° 42′ and Height above M. S. L. 1765 feet.

Ring	Number of Sector																Hor. Sum	Continuous Sum	F.	F × Hor. Sum
	West Roman + Italic −								East Roman − Italic +											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
30																				
29																				
28																				
27																				
26																				
25								·17	·17								0·00		·995	
24								·17	·17								0·00		·992	
23								·17	·17								0·00		·988	
22								·17	·17								0·00		·983	
21	·16	·16	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	−0·02	− 0·02	·976	−0·02
20	·16	·16	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	−0·02	− 0·04	·965	−0·02
19	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·16	·16	·16	·17	+0·03	− 0·01	·951	+0·03
18	·17	·17	·17	·17	·17	·17	·17	·17	·17	·16	·15	·16	·16	·15	·15	·17	+0·10	+ 0·09	·930	+0·09
17	·17	·17	·17	·17	·17	·17	·17	·17	·17	·16	·14	·14	·15	·15	·15	·17	+0·13	+ 0·22	·900	+0·12
16	·17	·17	·17	·17	·17	·17	·17	·17	·17	·16	·14	·14	·15	·15	·15	·17	+0·13	+ 0·35	·859	+0·11
15	·16	·17	·17	·17	·17	·17	·16	·17	·18	·16	·14	·14	·13	·14	·14	·15	+0·16	+ 0·51	·801	+0·13
14	·16	·17	·17	·17	·17	·17	·17	·17	·16	·14	·14	·13	·13	·14	·14	·14	+0·23	+ 0·74	·721	+0·17
13	·16	·17	·16	·15	·15	·17	·17	·16	·16	·14	·14	·14	·13	·13	·13	·14	+0·18	+ 0·92	·618	+0·11
12	·16	·16	·16	·14	·17	·15	·16	·16	·15	·14	·15	·14	·16	·15	·17	·15	+0·05	+ 0·97	·493	+0·02
11	·17	·16	·15	·14	·14	·15	·13	·15	·15	·14	·15	·15	·17	·18	·19	·19	−0·13	+ 0·84	·358	−0·05
10	·15	·14	·13	·12	·12	·11	·08	·12	·08	·09	·12	·14	·14	·16	·17	·13	−0·06	+ 0·78	·234	−0·01
9	·12	·16	·17	·13	·12	·11	·08	·11	·07	·08	·11	·13	·13	·14	·12	·14	+0·08	+ 0·86	·139	+0·01
8	·12	·15	·15	·14	·13	·12	·09	·08	·05	·05	·08	·14	·16	·15	·17	·18	0·00	+ 0·86	·077	0·00
7	·11	·09	·11	·07	·19	·14	·16	·11	·05	·03	·04	·09	·17	·15	·15	·09	+0·21	+ 1·07	·040	+0·01
6	·14	·15	·02	·02	·08	·06	·09	·08	·12	·12	·03	·06	·18	·16	·13	·08	−0·24	+ 0·83	·020	0·00
5	·20	*·02*	·01	·02	·03	·05	·06	·14	·98	·92	·35	·04	·14	·10	·13	·12	−2·29	− 1·46	·010	−0·02
4	*·08*	*·65*	*·64*	·34	·00	·24	·32	·78	1·58	1·45	·65	·04	*·03*	*·18*	*·46*	*·25*	−3·17	− 4·63	·005	−0·02
3	*·51*	*·79*	*·74*	·48	·01	·25	·28	·74	·85	·96	·64	·36	·11	*·40*	*·53*	*·41*	−2·85	− 7·48	·003	−0·01
2	*·75*	*·92*	*·61*	·14	·08	·30	·21	·07	·38	·75	·55	·30	·15	·02	*·27*	*·82*	−2·54	−10·02	·001	0·00
1	*·71*	*·88*	*·12*	·16	·12	·09	·13	·06	·28	·27	·12	·05	*·19*	*·01*	*·04*	*·92*	−0·71	−10·73	·001	0·00
																				+0·65

DEFLECTIONS AT LATITUDE STATION IN THE MERIDIAN.

REGION No. 1.—HIMALAYA MOUNTAINS.

1	2	2a	3	4	5	6	7
					A − G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = *C*	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6-Col. 4
		feet	"	"	"	"	"
18	Dehra Dún ...	2289	− 86	− 18	− 37	− 31	− 13
68	Mussoorie ...	6937	− 86	− 17	− 37	− 30	− 13
133	Birond	6967	− 74	− 14	− 44	− 38	− 24
181	Kurseong ...	4428	−103	− 23	− 51	− 46	− 23
67	Murree	7253	− 45	− 10	− 20	− 12	− 2
183	Lambatach ...	10474	− 71	− 9	− 34	− 27	− 18
						Mean	− 16

DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION No. 2.—PLAINS AT THE FOOT OF THE HIMALAYA.

1	2	2a	3	4	5	6	7
					A − G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = *C*	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6-Col. 4
		feet	"	"	"	"	"
41	Kaliana ...	828	− 58	− 3	− 7	− 1	+ 2
224	Siliguri ...	401	− 84	− 11	− 22	− 18	− 7
166	Jalpaiguri ...	280	− 77	− 8	− 6	− 1	+ 7
...	Pathardi ...	320	− 64	− 3	− 19	− 14	− 11
						Mean	− 2

DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION No. 3.—NORTH-EAST INDIA.

1	2	2a	3	4	5	6	7
					A — G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = *C*	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6–Col. 4
		feet	"	"	"	"	"
13	Calcutta	18	− 51	0	+ 1	+ 4	+ 4
14	Chendwar ...	2817	− 43	0	+ 3	+ 7	+ 7
143	Chanduria ...	160	− 63	− 2	+ 4	+ 9	+ 11
37	Hurilaong ...	1378	− 37	+ 2	+ 11	+ 15	+ 13
43	Kanakhera ...	416	− 39	0	+ 5	+ 10	+ 10
32	Gurwani	2083	− 35	+ 1	+ 3	+ 7	+ 6
72	Nimkar	486	− 44	− 1	0	+ 5	+ 6
188	Madhupur ..	92	− 47	− 1	+ 4	+ 8	+ 9
130	Bansgopal ...	677	− 44	− 1	− 5	+ 1	+ 2
...	Sora	400	− 44	0	+ 8	+ 11	+ 11
						Mean	+ 8

DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION No. 4—CENTRAL INDIA.

1	2	2a	3	4	5	6	7
					A — G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = *C*	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6–Col. 4
		feet	"	"	"	"	"
44	Kankra ...	1652	− 35	− 1	− 1	+ 4	+ 5
50	Kesri ...	1487	− 31	+ 1	+ 6	+ 10	+ 9
93	Rewat ...	1542	− 28	0	+ 1	+ 6	+ 6
222	Saugor ...	2033	− 29	+ 1	+ 1	+ 4	+ 3
76	Pahargarh ...	1641	− 30	+ 1	0	+ 4	+ 3
149	Daiadhari ...	1867	− 31	0	+ 1	+ 5	+ 5
						Mean	+ 5

DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION NO. 5.—NORTH-WEST INDIA.

1	2	2a	3	4	5	6	7
					A − G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = C	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6–Col. 4
		feet	″	″	″	″	″
201	Oria	4200	− 35	+ 1	− 3	+ 1	0
174	Khankharia ...	362	− 37	0	+ 2	+ 6	+ 6
215	Rojhra	518	− 35	− 1	0	+ 4	+ 5
194	Mooltan ...	420	− 36	− 1	− 3	+ 4	+ 5
124	Amritsar ...	770	− 45	− 1	+ 4	+ 11	+ 12
101	Tasing	2050	− 33	+ 1	0	+ 6	+ 5
120	Akbar	641	− 29	− 1	− 5	+ 2	+ 3
122	Alum Khan ...	67	− 36	− 1	− 1	+ 3	+ 4
95	Sawaipur ...	697	− 30	0	− 1	+ 6	+ 6
134	Bithnok ...	774	− 27	+ 1	+ 3	+ 8	+ 7
117	Agra	550	− 35	0	− 5	0	0
45	Karachi	35	− 45	− 2	0	+ 4	+ 6
233	Thob	856	− 32	− 1	− 3	+ 3	+ 4
213	Rangitgarh ...	900	− 44	− 5	− 6	+ 2	+ 7
38	Isanpur ...	874	− 35	− 1	− 4	+ 3	+ 4
89	Ramthal ...	951	− 27	+ 1	0	+ 4	+ 3
53	Khimuana ...	731	− 33	0	− 3	+ 3	+ 3
232	Telu	470	− 29	0	+ 1	+ 7	+ 7
73	Noh	710	− 38	− 1	0	+ 5	+ 6
17	Datairi	767	− 40	− 1	− 6	0	+ 1
106	Usira	810	− 33	0	− 6	− 1	− 1
						Mean	+ 4

DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION No. 7.—WESTERN INDIA.

1	2	2a	3	4	5	6	7
					A − G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = C	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6-Col. 4
		feet	"	"	"	"	"
155	Deesa	443	− 38	− 1	− 8	− 4	− 3
145	Chaniana	953	− 35	− 3	− 11	− 8	− 5
147	Colaba	75	− 37	0	− 10	− 9	− 9
193	Mandvi	4121	− 37	− 1	− 3	− 2	− 1
16	Damargida ...	1941	− 35	0	− 2	− 1	− 1
52	Khanpisura ...	2751	− 38	− 3	− 8	− 7	− 4
5	Badgaon	1128	− 33	0	− 8	− 5	− 5
34	Harnasa	1816	− 31	0	− 3	0	0
107	Valvadi	1125	− 29	+ 1	− 6	− 4	− 5
19	Deo Dongri ...	1727	− 30	0	− 5	− 1	− 1
59	Ladi	1875	− 31	− 1	− 5	− 2	− 1
80	Peddapad... ...	1090	− 34	0	− 6	− 6	− 6
81	Pialmudi	1869	− 34	0	− 5	− 5	− 5
62	Majala	2613	− 35	0	− 1	− 1	− 1
199	Nitali	2289	− 33	0	− 4	− 3	− 3
109	Voi	1439	− 34	− 1	− 5	− 4	− 3
70	Navalur	2445	− 38	− 1	− 3	− 3	− 2
66	Mavinhunda ...	2582	− 33	+ 2	0	+ 1	− 1
49	Kem	1951	− 35	0	− 3	− 2	− 2
57	Kundgol	2147	− 36	+ 1	− 1	− 1	− 2
102	Thikri	851	− 30	0	+ 1	+ 4	+ 4
...	Dangarvadi ...	96	− 44	− 2	− 9	− 7	− 5
...	Kunkavav ...	591	− 38	0	− 2	+ 1	+ 1
						Mean	− 3

DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION No. 8.—EASTERN INDIA.

1	2	2a	3	4	5	6	7
					A − G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = C	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6–Col. 4
		feet	"	"	"	"	"
135	Bolarum ...	1971	− 38	− 1	− 6	− 5	− 4
239	Waltair ...	200	− 62	− 6	− 9	− 8	− 2
184	Lingmara ...	1400	− 38	− 1	− 8	− 5	− 4
148	Cuttack ...	133	− 55	− 3	− 9	− 7	− 4
197	Naharmau ...	1940	− 31	0	− 5	− 2	− 2
192	Mal ...	483	− 58	− 6	−10	− 9	− 3
203	Pathaidi ...	879	− 42	− 1	− 3	0	+ 1
202	Parampudi ...	684	− 49	− 2	− 6	− 5	− 3
151	Danapa ...	150	− 44	− 1	0	0	+ 1
198	Nialamari ...	1144	− 42	− 1	− 8	− 7	− 6
160	Dhulipalla ...	245	− 44	− 1	− 3	− 3	− 2
200	Ongole ...	250	− 45	− 1	− 4	− 4	− 3
154	Darutippa ...	195	− 45	− 1	− 3	− 3	− 2
218	Sanjib ...	2142	− 66	− 9	− 6	− 6	+ 3
214	Rawal ...	874	− 56	− 3	− 4	− 3	0
236	Vanakonda ...	1664	− 42	− 1	− 7	− 6	− 5
238	Vizagapatam ...	181	− 61	− 5	− 6	− 5	0
						Mean	− 2

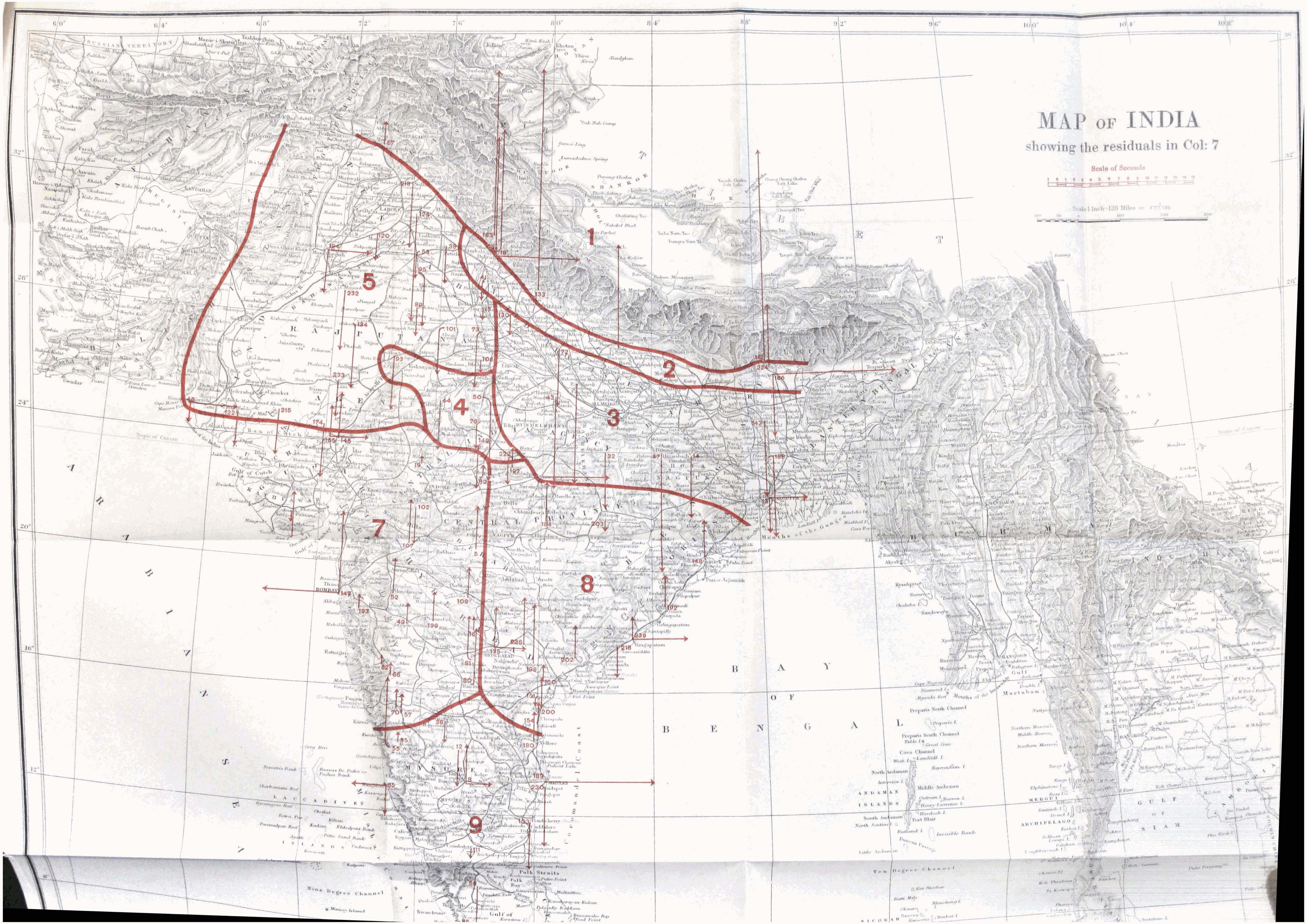
DEFLECTIONS AT LATITUDE STATIONS IN THE MERIDIAN.

REGION No. 9.—SOUTHERN INDIA.

1	2	2a	3	4	5	6	7
					A − G		
No.	Name	Height	Topographical Deflection	Topographical Deflection Compensated = C	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 6–Col. 4
		feet	"	"	"	"	"
58	Kutiparai ...	347	− 50	− 4	+ 2	+ 3	+ 7
65	Mangalore ...	186	− 42	− 1	+ 3	+ 2	+ 3
8	Bangalore ...	3126	− 37	− 1	− 5	− 5	− 4
230	St. Thomas' Mt. ...	250	− 41	− 1	+ 6	+ 5	+ 6
85	Punnæ ...	48	− 54	− 4	+ 2	− 1	+ 3
103	Teruvendipuram ...	...	− 40	− 1	+ 6	+ 4	+ 5
111	Yettimalai ...	617	− 43	− 1	+ 2	0	+ 1
180	Kistama ...	458	− 42	0	− 2	− 3	− 3
35	Honnavalli ...	2775	− 37	− 1	− 2	− 2	− 1
69	Namthabad ...	1169	− 35	− 1	− 1	− 1	0
55	Koramur ...	2527	− 36	+ 1	− 5	− 6	− 7
12	Bommasandra ...	2005	− 31	+ 2	+ 6	+ 6	+ 4
163	Gudali ...	292	− 42	0	+ 1	0	0
36	Honnur ...	1579	− 32	+ 1	+ 3	+ 3	+ 2
						Mean	+ 1

DEFLECTIONS AT LONGITUDE STATIONS IN PRIME VERTICAL.

1	2	3	4	5	6	7	8
					(A − G) cos λ		
Reference Letter	Name	Height	Topographical Deflection	Topographical Deflection Compensated = *C*	Everest's Spheroid	Bessel-Clarke Spheroid	Residual Col. 7–Col. 5
		feet	"	"	"	"	"
	Agra ...	550	− 17	0	...	...	...
	Amritsar ...	770	− 30	− 1	...	...	...
R	Bangalore ...	3126	0	0	− 3	− 3	− 3
	Bellary ...	...	− 5	0	...	...	..
L	Bolarum ...	1971	− 2	0	− 3	− 3	− 3
E	Calcutta ...	18	− 7	0	− 10	− 4	− 4
O	Colaba ...	75	− 29	− 4	+ 7	+ 4	+ 8
P	Deesa ...	443	− 20	− 2	− 3	− 6	− 4
C	Dehra Dún ...	2240	− 57	− 13	− 22	− 22	− 9
G	Jalpaiguri ...	280	− 8	0	− 18	− 13	− 13
N	Jubbulpore ...	1306	− 9	− 1	− 9	− 8	− 7
A	Kalianpur ...	1765	− 11	+ 1	...	...	...
B	Karachi ...	35	− 16	− 1	− 1	− 6	− 5
S	Madras ...	54	+ 31	+ 6	− 7	− 5	− 11
Q	Mangalore ...	186	− 29	− 3	+ 2	+ 1	+ 4
	Multan ...	420	− 11	+ 1	...	...	...
	Peshawar ...	1100	− 9	+ 4	...	...	...
	Punnæ ...	48	0	+ 1	...	...	...
M	Waltair ...	200	+ 17	+ 6	− 3	0	− 6



MAP OF INDIA
showing the residuals in Col: 7
Scale of Seconds
BAY OF BENGAL
ARABIAN SEA