SURVEY OF INDIA

TECHNICAL REPORT 1948-49

PART III—GEODETIC WORK

PUBLISHED BY ORDER OF
THE SURVEYOR GENERAL OF INDIA

PRINTED AT THE OFFICE OF THE GEODETIC & TRAINING CIRCLE
SURVEY OF INDIA, DEHRA DŪN, INDIA, 1950.

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INTRODUCTION

1. The present volume is the second of the series of Technical Reports issued during the post-war period. The first volume entitled "Technical Report 1947, Part III—Geodetic Work" covers the period 1st October 1939 to 30th September 1947. The present report gives a detailed account of the activities of the Geodetic and Research Branch (formerly known as the Survey Research Institute) during the period 1st October 1947 to 31st March 1949. From 1925 to 1939 an account of the geodetic work of the Survey of India has been published in the annual Geodetic Reports. A brief report was issued for 1940 as well. The following is a review of the work carried out during the period under report.

2. *Geodetic Triangulation.*—(Chapter I). A good deal of the geodetic triangulation of India is of secondary quality (see Chart I). This and the topographical triangulation based on it, although adequate for providing a framework for the one-inch topographical map of India, are quite insufficient to meet the needs of large scale cadastral, hydro-electric, irrigation and other development surveys both as regards density of control points and the precision of basic and control data. As an example, the triangulation carried out in Kulu (Punjab) to serve as a basis for large scale revenue maps and that carried out in Nepāl in connection with the Kosi Irrigation Project, were both without a proper geodetic basis. Similarly for the surveys which are urgently required for the development of the Port of Kandla in Kutch, geodetic and topographical triangulation of the requisite accuracy does not exist. A start is therefore being made with the strengthening of the secondary triangulation in the Kandla area by the measurement of a geodetic base, the observation of twin Laplace at 4 stations of this series and the re-observations of the angles of triangles which had large triangular errors.

A systematic programme of re-observation of the entire secondary triangulation in India extending over a period of years is envisaged. In some areas it may be more economical and convenient to replace geodetic triangulation by high precision traverses. With this end in view, the necessary personnel are being trained. It will, however, take some time before any tangible results are obtained.

Large scale maps are also likely to be required for the development of the Andaman and Nicobar Islands for the resettlement of refugees from Pakistan. Details of the existing triangulation and maps of these islands are, therefore, put on record and recommendations for future work are made.

3. *Levelling.*—(Chapter II). The levelling under report has added 905 miles in one direction only to the new High Precision level net. Out of a total estimated mileage of 15,800 miles for this

net, levelling of 4,600 miles still remains to be carried out. About 400 miles of levelling of precision were also run to meet extra-departmental needs.

Two of the level lines have yielded some interesting results. A line from Roorkee to Hardwar has indicated an upwarping of the Siwalik axis at the rate of about one inch in 40 years. One line was run from Burdwān to Dublat at the request of the River Surveyor to the Commissioners for the Port of Calcutta for providing new reference bench-marks along the Hooghly for the tide-gauge stations. This has given useful data about the subsidence of levels in South Bengal.

4. *Gravity.*—(Chapter III). Observations have been made at 101 new stations with the Frost Gravimeter in the Rāniganj coal-fields area and in the Nagpur area. The work in the Nagpur area is still in progress. The results in the Rāniganj coal-fields area are discussed and some interesting features are brought to light. While the present spacing of stations can not locate anything like the actual coal seams, it can help in structural investigations such as the possibility of extension of the Rāniganj coal bearing series under the alluvium and in pointing out areas for more intensive study.

Thirty-six old pendulum stations have also been re-observed, and useful information gained about the precision of older work.

A noteworthy event has been the connection of the base station at Dehra Dūn to the group of 5 stations at Delhi recently observed by Dr. G. P. Woollard of the Woods Hole Oceanographic Institution (U.S.A.) as part of his world net of gravity stations. The details of this connection are given in para 38.

Isostatic anomalies have been calculated for gravity stations in Thailand.

5. *Deviation of the Vertical.*—(Chapter IV). Two weak sections of the geoid, one in Central India and the other in South India have been strengthened by observing deflections at stations spaced about 15 to 20 miles apart. As a result, the closing errors of the two geoidal circuits have greatly improved.

The results of Laplace observations at 1 station in Nepāl, 3 pairs of stations in Central India, 2 stations in Mārwār, and 2 stations in South India are also discussed.

6. *Headquarters Routine.*—(Chapter V and VI). The tidal prediction, seismic and meteorological observations at Dehra Dūn have been continued. It has not been possible to restart the Dehra Dūn Magnetic Observatory due to financial stringency and the programme of re-observation at magnetic repeat stations has also remained in abeyance.

Some interesting observations for determination of variation of magnetic force at different levels were, however, made in the Kolar Goldfields to test the modern theories of Earth's magnetism.

7. *Computing Office.*—(Chapter VII). A start has been made with the adjustment and publication of topographical triangulation and traverse data all over India. Due to shortage of trained personnel, the progress is slow. The job is estimated to take 30 computers about 30 years to complete.

8. *Research and Technical Notes.*—(Chapter VIII). In Section I the problems associated with Mean Sea-Level in India and its fluctuations are discussed. In Section II the results of recent levelling to detect subsidence of levels from Calcutta to Diamond Harbour and to Dublat are considered. There appears to be evidence of a general subsidence but to determine the rate of subsidence relevelling at frequent intervals say every two to five years is necessary. Section III gives the definitions of the various geoids in use in India and the data on which they are based.

9. *Future Programme.*—The financial stringency is likely to impede the progress of geodetic and geophysical work for sometime in the future. It is, however, hoped that it will be possible to carry on the programme of strengthening the secondary triangulations by the measurement of new bases, re-observation of angles where necessary and the provision of Laplace control, beginning with areas where there is an urgent demand for large scale surveys. In order to meet the urgent requirements of Central and Provincial Governments for secondary levelling, the completion of the new High Precision net will inevitably be delayed. It is intended to continue the observation of the new 10-mile network of gravimetric stations.

The question of restarting the Magnetic Observatory at Dehra Dūn is under the consideration of the Government of India. When the observatory gets re-opened the programme of observation of magnetic elements at Repeat stations will be resumed.

Some work on the redetermination of tidal constants to improve predictions is also contemplated.

It is also intended to continue the study of changes of levels associated with major geological faults and thrust planes, the rise of Siwalik axis and the downwarping of deltaic area of Bengal by carrying out levelling at periodical intervals.

DEHRA DŪN, October, 1950.

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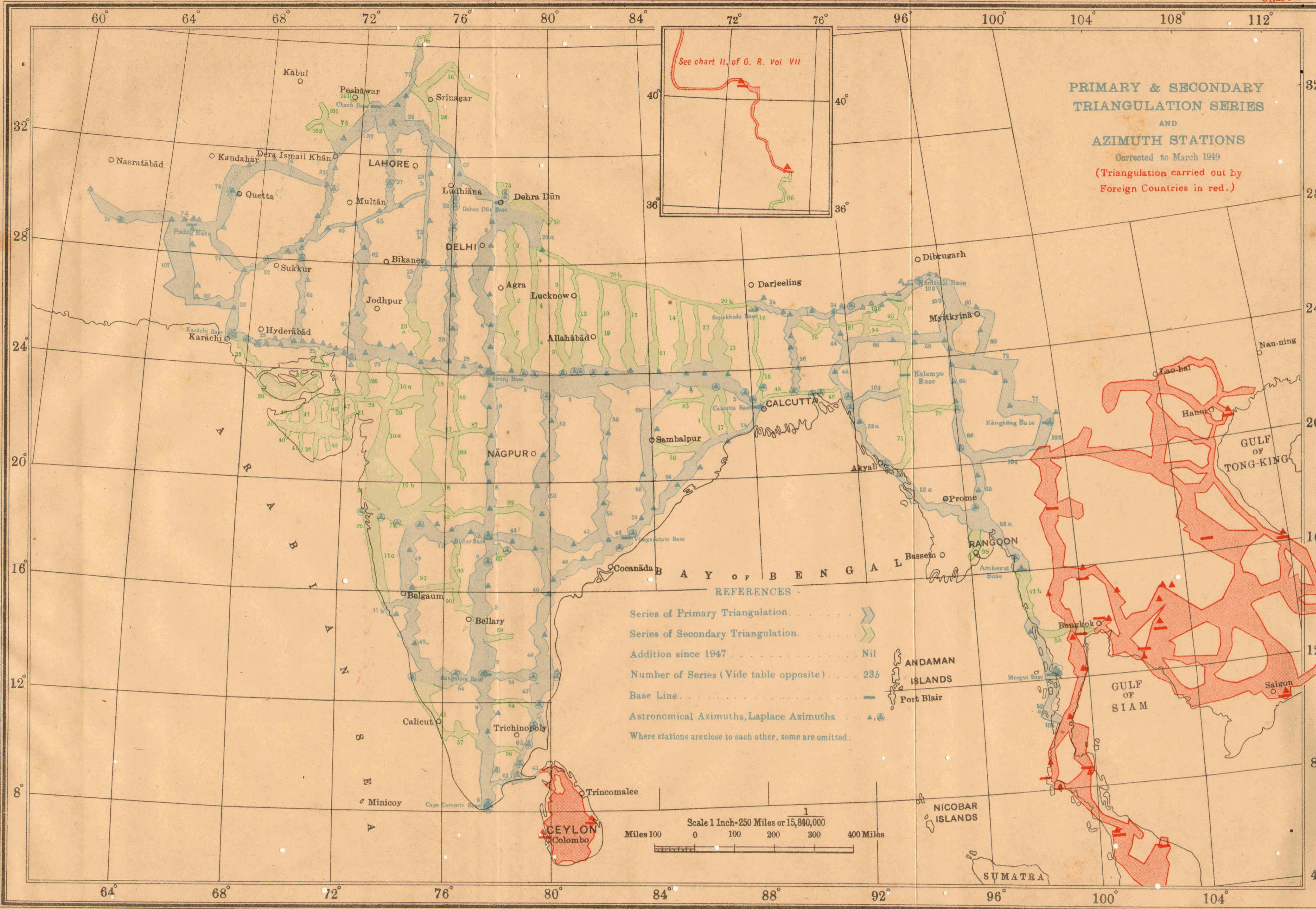
Primary and Secondary Triangulation Series

No.	Name of Series	Season	± m	± p	Instrument
	Primary Series		″	*ft.*	*inches*
5	Calcutta Longitudinal	1864–69	0.369	2.23	36 & 24
6	Great Arc Meridional, Section 24°–30° ..	1835–66	0.708	4.26	36
7a	Bombay Longitudinal, East of 75° ..	1862–63	0.844	2.19	24
8	Great Arc Meridional, Section 18°–24° ..	1837–41	0.567	1.26	36
9	Great Arc Meridional, Section 8°–18° ..	1866–74	0.390	1.80	24
11b	South Konkan Coast ..	1866–67	2.176	1.62	24
20a	North-East Longitudinal, West of 80° ..	1850–51	0.446	1.36	24
22	North West Himālaya	1848–53	0.641	2.15	24
23b	Gurhāgarh Meridional between 26½°–32½° ..	1859–62	0.914	1.44	24
24	East Coast ..	1848–63	0.608	1.58	24
25	Karāchi Longitudinal	1849–55	0.558	1.88	36
32	Great Indus ..	1853–61	0.359	1.74	36 & 24
33	Rahūn Meridional ..	1853–63	0.327	1.24	24
34	Assam Longitudinal (See 108) ..	1854–60	0.579	1.52	24
37	Jogi-Tila Meridional ..	1855–62	0.481	1.67	36 & 24
43	Bihar Longitudinal ..	1860–72	0.311	1.21	36 & 24
44	Eastern Frontier or Shillong Meridional ..	1860–64	0.409	1.24	24
45	Sutlej	1861–63	0.346	1.74	36
46	Madras Meridional and Coast ..	1860–68	0.426	1.28	36 & 24
49	Mangalore Meridional	1863–73	0.440	1.14	24
52a	Burma Coast (See 106)	1864–82	0.380	1.27	24
53	Jubbulpore Meridional	1864–67	0.340	1.04	36
54	Madras Longitudinal .	1865–73	0.384	1.23	24
56	Brahmaputra Meridional ..	1868–74	0.564	1.02	24
58	Bilāspur Meridional ..	1869–73	0.302	0.98	36 & 24
62	Jodhpur Meridional ..	1873–76	0.291	1.11	24
63	South-East Coast ..	1874–80	0.522	1.33	24
64	Eastern Sind Meridional ..	1876–81	0.244	1.25	24
66	Mandalay Meridional (See 109)	1889–95	0.418	1.46	12
68	Manipur Longitudinal	1894–99	0.453	1.45	12
69	Makrān Longitudinal ..	1895–97	0.285	0.92	12
72	Great Salween (See 105)	1900–11	0.404	4.28	12
74	Kalāt Longitudinal ..	1904–08	0.365	3.15	12
76	North Baluchistān ..	1908–10	0.221	1.82	12
77	Gilgit ..	1909–11	0.443	2.62	12
80	Upper Irrawaddy ..	1909–11	0.596	3.14	12
85	Sambalpur Meridional	1911–14	0.250	1.28	12
103	Chittagong ..	1928–30	0.453	2.181	5½
104	Mong Hsat ..	1929–31	0.441	1.67	12 & 5½ Wild
105	Great Salween ..	1929–31	0.682	3.04	12 & 5½ Wild
106	Burma Coast ..	1930–31	0.206	1.29	12
107	Dālbandin ..	1931–32	0.472	4.55	5½ Wild
108	Assam Longitudinal ..	1934–36	0.426	1.034	5½ Wild
109	Mandalay Meridional ..	1936–37	0.422	2.900	5½ Wild
	Secondary Series				
1	South Pārasnāth Meridional ..	1836–39	3.308	9.98	18
2	Budhon Meridional ..	1833–43	2.242	7.47	18 & 15
3	Amūa Meridional ..	1834–38	1.647	4.71	18
4	Rangir Meridional ..	1834–41	1.643	7.52	18 & 15
7b	Bombay Longitudinal West of 75° ..	1837–39	0.844	2.19	15
10a	Singi Meridional 21°–25°	1860–62	1.187	1.26	18
10b	Singi Meridional 19°–21°	1842–46	1.187	1.26	15
11a	South Konkan Coast 15½°–19° ..	1842–44	2.176	1.62	15
12	Karāra Meridional ..	1843–45	1.507	3.46	18 & 15
13	North Malūncha Meridional ..	1844–46	1.266	3.69	18 & 15
14	Chendwār Meridional ..	1844–46	0.841	1.51	36, 24 & 18
15	Gora Meridional ..	1845–47	0.973	3.09	15
16	Calcutta Meridional ..	1845–48	1.173	1.52	18
17	South Malūncha Meridional ..	1845–53	1.606	1.49	24 & 18
18	Khānpisura Meridional	1845–48	1.227	2.11	24 & 15
	Secondary Series—*Contd.*		″	*ft.*	*inches*
19	Gurwani Meridional ..	1846–47	1.165	2.57	24 & 1
20b	North-East Longitudinal East of 80° ..	1846–51	0.446	1.36	36, 24 & 15
21	Hurilāong Meridional ..	1848–52	1.502	2.42	24 & 1
23a	Gurhāgarh Meridional 24½°–26½° ..	1848–50	0.914	1.44	18 & 1
26	Abu Meridional ..	1851–52	0.617	1.53	18
27	North Pārasnāth Meridional ..	1851–52	0.895	2.10	24
28	Kāthiāwār Meridional	1852–56	0.990	2.01	18
29	Gujarāt Longitudinal ..	1852–62	0.859	1.37	18
30	Kāthiāwār Longitudinal ..	1853	1.481	1.66	18
31	Sābarmati ..	1853–54	1.348	0.91	18
35	Cutch Coast ..	1855–58	0.986	1.80	18
36	Kashmir Principal ..	1855–60	0.894	2.48	14 Vernier
38	Sambalpur Longitudinal ..	1856–57	0.806	1.48	14 Vernier
39	(Cutch) Coast Line ..	1856–60	0.975	1.44	18 & 1
40	Kāthiāwār Meridional No. 1 ..	1858–59	0.930	0.87	18
41	Kāthiāwār Meridional No. 2 ..	1859–60	1.247	1.39	18
42	Kāthiāwār Meridional No. 3 ..	1859–60	0.969	3.36	18
47	Kāthiāwār Meridional No. 4 ..	1863–64	1.154	..	18
48	East Calcutta Longitudinal ..	1863–69	0.379	0.96	24
50	Kumaun and Garhwāl	1864–65	1.742	1.81	14 & 12 Vernier
51	Nāsik ..	1864–65	2.033	0.78	14 & 6
52b	Burma Coast 14½°–16°	1876–77	0.380	1.27	24
55	Assam Valley Triangulation ..	1867–78	1.690	1.60	14, 12 & 10
57	Coimbatore No. 1 ..	1869–71	1.547	2.50	14
59	Cuddapāh ..	1871–72	0.826	1.32	10
60	Hyderabad ..	1871–72	1.405	0.78	24 & 7
61	Malabar Coast ..	1872–80	1.532	1.17	14 & 12 Vernier
65	Siam Branch ..	1878–81	3.711	2.55	12
67	Mong Hsat ..	1891–93	3.054	2.71	14, 12 & 10
70	Mandalay Longitudinal	1899–1900	1.696	1.00	8
71	Manipur Meridional ..	1899–1902 & 1915–1916	0.750	2.22	12
73	Kidarkanta ..	1902–03	1.323	2.17	12 & 7
75	"Baluchistān" (Bannu)	1908–09	1.348	2.97	12 & 8
78	Khāsi Hills ..	1909–13	2.038	0.76	8
81	Jaintia Hills ..	1910–11	0.980	0.49	8
82	Bhir ..	1911–12	0.794	2.49	8
83	Rānchi ..	1911–12	1.840	0.61	8
84	Villupuram ..	1911–12	1.184	0.46	8
86	Indo-Russian Connection ..	1912–13	2.790	2.17	0
87	Khandwa ..	1912–13	0.990	1.71	8
88	Ashta ..	1913–14	1.048	1.33	8
89	Buldāna ..	1913–14	0.304	0.98	8
90	Naldrug ..	1913–14	1.465	1.91	8
91	Nāga Hills ..	1913–14	0.913	2.17	12
92	Middle Godāvari ..	1914–15	0.913	0.72	8
93	Kohima ..	1913–15	1.094	1.48	12 & 8
94	Cāchār ..	1914–15	1.077	1.17	12
95	Bombay Island ..	1911–14	..	..	8
96	Madura ..	1916–17	1.148	1.49	8
97	Bāgalkot ..	1916–17	0.701	1.15	8
99	Rangoon ..	1925–27	1.246	..	12
100	Kurram ..	1927–28	2.096	3.80	3½ Wild
101	Peshāwar ..	1927–28	1.267	5.56	3½ Wild
102	North Waziristān ..	1927–28	1.895	2.16	3½ Wild

± m root-mean-square error of an unadjusted horizontal angle (in seconds).

± p root-mean-square error of the unadjusted height difference between two stations (in feet).

Chart I



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CHAPTER I

TRIANGULATION

BY B. L. GULATEE, M.A. (CANTAB.)

1. **Geodetic Triangulation in India.**—Chart I shows the Primary and Secondary Triangulation of India which has often been loosely described as Geodetic Triangulation.

The bulk of this work was carried out between 1802 and 1882 when the skeleton framework of the Geodetic Triangulation was reckoned to be complete and the net was adjusted by simultaneous grinding for getting final values of co-ordinates—a process that took 20 years to complete. The Survey of India department was reorganized in 1905 and it was asked to concentrate its energies on a new series of topographical maps of 1 inch to 1 mile scale. Accordingly, very little was done in the way of Principal triangulation after 1905—only a few series being observed, mainly in Baluchistān and Burma. A number of secondary series were observed between 1909 and 1917 with a view to filling in the gaps between primary series; and a vast amount of topographical triangulation was carried out to provide the framework for 1-inch maps.

The stations of the broad network of Geodetic Triangulation are protected monuments and their co-ordinates and heights have been printed in triangulation pamphlets. While the Primary triangulation was of the same order of accuracy as that in Europe in its time, it cannot compete with good triangulation executed now-a-days by modern instruments. Some of the stations are over a century old and have been destroyed and can only be restored by observations to surrounding stations. The triangulation is also weak in certain areas especially in the plains of India where high towers had to be erected to secure visibility of rays. There are sure to be large local errors in places, especially between the centres of weak series running parallel to each other at a comparatively short distance apart. Accordingly there are considerable areas inside India where re-observation and strengthening of secondary series is necessary.

As an example the problem arose lately to demarcate the boundary between East and West Bengal. The old cadastral 16-inch maps in this area were based on data unrelated to the primary triangulation of India. The only series running through this area is Calcutta Meridional Series (No. 16) executed under very difficult circumstances in the year 1845–48, as the country is a perfectly level plain abounding in tall trees. It is of secondary quality and most of the stations are tower stations ranging in height from 26 to 44 feet. A recent reconnaissance of this series revealed that most of these stations had disappeared and when the boundary is demarcated, quite a number of high precision traverses will be necessary making use of the sparse G.T. control as far as possible.

The stations of the G.T. framework in a chain are about 18 to 20 miles apart but the chains themselves are about 100 to 200 miles apart. For topographical maps of 1-inch and smaller scales, this has been supplemented by topographical triangulation and traverse and the detail of the Indian sub-continent so far as the accuracy of 1-inch maps can show it, is in terms of this topographical framework.

2. Framework for Large Scale Maps.—As a basis for large scale and local projects, the precision of the existing topographical triangulation is generally not enough and the geodetic framework was not at all designed for this purpose, its stations being located in remote and not easily accessible places. In the plains high tower stations were used and these have been mostly damaged or destroyed. No serious primary traverses have been run in India as a substitute for geodetic triangulation.

The strengthening and extension of the G.T. triangulation and the provision of a sufficiently dense and precise framework to provide scale and azimuth in areas where there is likelihood of large scale work are important practical necessities which will entail years of planned work and labour.

There are numerous urgent demands now-a-days on the Survey of India for large scale maps and one of these is in the Kāthiāwār area for the development of the Port of Kandla. This area has so far not been covered even by 1-inch modern survey. Two secondary series Kutch Coast Series (No. 35) and Kutch Coast-line Series (No. 39) run through the area and it is proposed to strengthen them next field season by the measurement of a geodetic base and the observations of Laplace stations as shown in Chart II.

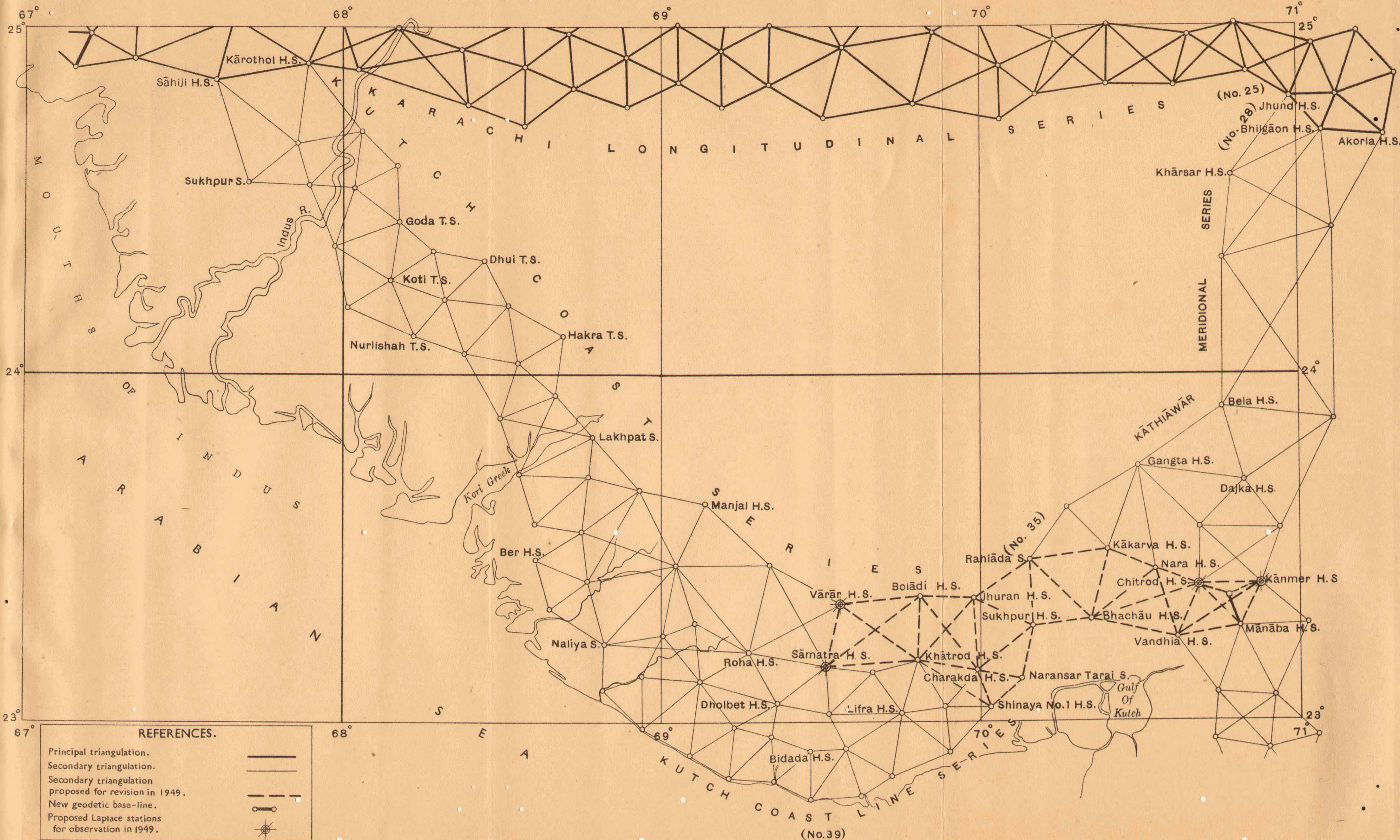
It will, however, be some time before a vigorous programme of systematic geodetic triangulation and primary traverse can be started. Observers are being trained in precision base measurements and in the use of Geodetic Wild and Tavistock theodolites. Hitherto, observations at night have been made to archaic Argand lamps, which work with kerosene oil. Some electric signal lamps have now been obtained from Messrs. Cooke Troughton and Simms and it is hoped that the use of these will contribute towards better precision of results.

3. Triangulation in Kulu.—Chart III shows the topographical triangulation in Kulu valley of East Punjab, carried out in 1946 to serve as a basis for large scale revenue maps required for revising the land settlement of the area, the last settlement having been carried out more than 60 years ago. It is of a reasonably good quality, but the area is so far removed from the geodetic triangulation network, that it has not been possible to use the G.T. either

GEODETIC TRIANGULATION IN KUTCH.

Scale 1 Inch = 19·729 Miles or 1:1250,000.

Chart II



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as a basis for the topographical triangulation or to control the errors of topographical triangulation in scale and bearing. The triangulation was based on an independent short base of 4-chain length measured with an accuracy of about 1/10,000 and an astronomical azimuth measured at Bijli h.s. The co-ordinates were derived from Saupar h.s., (of Beas–Chandrabhaga Series) which is a station of an exploratory triangulation emanating from stations Lasirmou H.S. (Lat. 34° 16′, Long. 77° 30′) and Parchakanri H.S. (Lat. 34° 01′, Long. 77° 27′) of Kashmīr Principal Series. The co-ordinates of this station can thus be in error by a considerable amount. The initial astronomical azimuth at Bijli h.s. of Kokhan h.s. used for the computation of the triangulation was corrected for Laplace. The correction applied was +23″. The astronomical azimuths observed at three other stations were also similarly corrected for Laplace and provided a satisfactory check. The triangulation is however without a proper geodetic basis and the extension of the Great Arc Meridional Series Section 24°–30° (No. 6) to join with the Kashmīr Principal Series (No. 36) would provide a G.T. connection in this area. It would also provide a support to the Kashmīr Series at its eastern end. There are, however, topographical and other difficulties in the execution of this work but it is on the programme of the Survey of India and it is hoped that it will be possible to take this up at not too distant a date.

4. Triangulation in Nepal.—In most of the catchment area of the Kosi river there was no triangulation of any kind when framework data was required in 1946 to control the surveys then urgently required in connection with the Kosi hydro-electric and irrigation project. In other areas where any triangulation existed it was of a sketchy nature and of poor quality. It was decided to carry out fresh triangulation from Sandakphu to Kātmāndu and to effect a connection with the G.T. to Ladnia T.S. (see Chart IV).

Again, as in the case of Kulu triangulation, for lack of any geodetic triangulation in the vicinity, the scale, bearing and initial co-ordinates for the new series of topographical triangulation had to be derived from Phalut h.s. and Sandakphu h.s., two stations of a very weak old triangulation (1879–80), which had its source in the North-East Longitudinal G.T. series about 100 miles away. The scale was controlled by measured short bases to prevent any serious accumulation of error and the connection to Ladnia T.S. is sufficient to put the co-ordinates of the new topographical triangulation in terms of G.T. series to which Ladnia T.S. belongs. Without a connection to G.T. bearing, or the observation of Laplace, however, it was not possible to put the azimuths of the new triangulation in terms of G.T.

It was not possible to observe at Ladnia T.S. to any of the surrounding G.T. stations due to the obstacles that have now surrounded this station. It was, therefore, decided to establish a Laplace station at Ladnia T.S. by observing at an auxiliary station close to it and to supplement it by observations at two other Laplace stations in the new series running towards Sandakphu h.s. It is unfortunate that owing to the failure of the wireless set, the programme had to be abandoned after making observations only at Tamarang h.s., which is a station of a subsidiary chain and the longitude of which is by no means well determined. The subsidiary chain is based on its own astronomical bearing and measured short base independent of the main chain.

Nearly all the old tower stations in this area have crumbled down and it appeared difficult to effect a connection of the main chain of topographical triangulation to a G.T. side. Fortunately, Bilby steel towers have now become available and it is contemplated to observe the quadrilateral Ladnia T.S., Sarunga h.s., Gidhmanau h.s. and Harpur T.S.

It is also proposed to strengthen the connection to Tamarang h.s., and remove other weaknesses in the main chain extending to Kātmāndu. From Kātmāndu it is proposed to carry the triangulation southwards and to effect a connection with the G.T. North-East Longitudinal Series at Sinaria T.S. and Bulakipur T.S. observing at stations Gehri Goor Thumka h.s., Kawachuri h.s. and Dhumi Danda h.s. (see Chart IV). The North-East Longitudinal Series is really a secondary series and it appears desirable to observe twin Laplace stations at Sinaria T.S.–Bulakipur T.S., and at Phalut h.s.–Sandakphu h.s. respectively.

5. **Triangulation in the Andamans and Nicobars.**—Lately, the development of the Andamans and Nicobar Islands for the purpose of resettlement of refugees from the Pakistan areas has assumed considerable importance and large scale mapping over there is being contemplated. It is therefore of importance to record what exists in the way of control framework in those areas and what further action is needed.

(*a*) *Andaman Islands.*—The datum station for latitudes and longitudes is the astronomical observatory on Chatham Island, where very elaborate astronomical observations were carried out by Mr. Nicholson of the Survey of India in 1861. Latitudes were determined from 162 meridional zenith distances and longitudes were obtained directly with respect to Greenwich from 41 lunar culminations and 180 lunar zenith distances. The actual values obtained were :

Latitude 11° 41′ 13″·00 N.

Longitude 92° 42′ 44″·00 E.

The triangulation (see Chart V) was executed by Capt. J. R. Hobday in 1883–86 with a 10-inch theodolite by Troughton and Simms. It was based on the astronomical co-ordinates of the above observatory as determined about 22 years previously. A base about ½ mile long was measured in 1883 with 5 rods of well seasoned teak wood prepared locally. These rods were 10 feet 2 inches long and 2 inches square in section and were standardized against an iron standard bar supplied by the G.T. Survey Office at Dehra Dūn. The rods were not varnished or protected from damp in any way, nor were

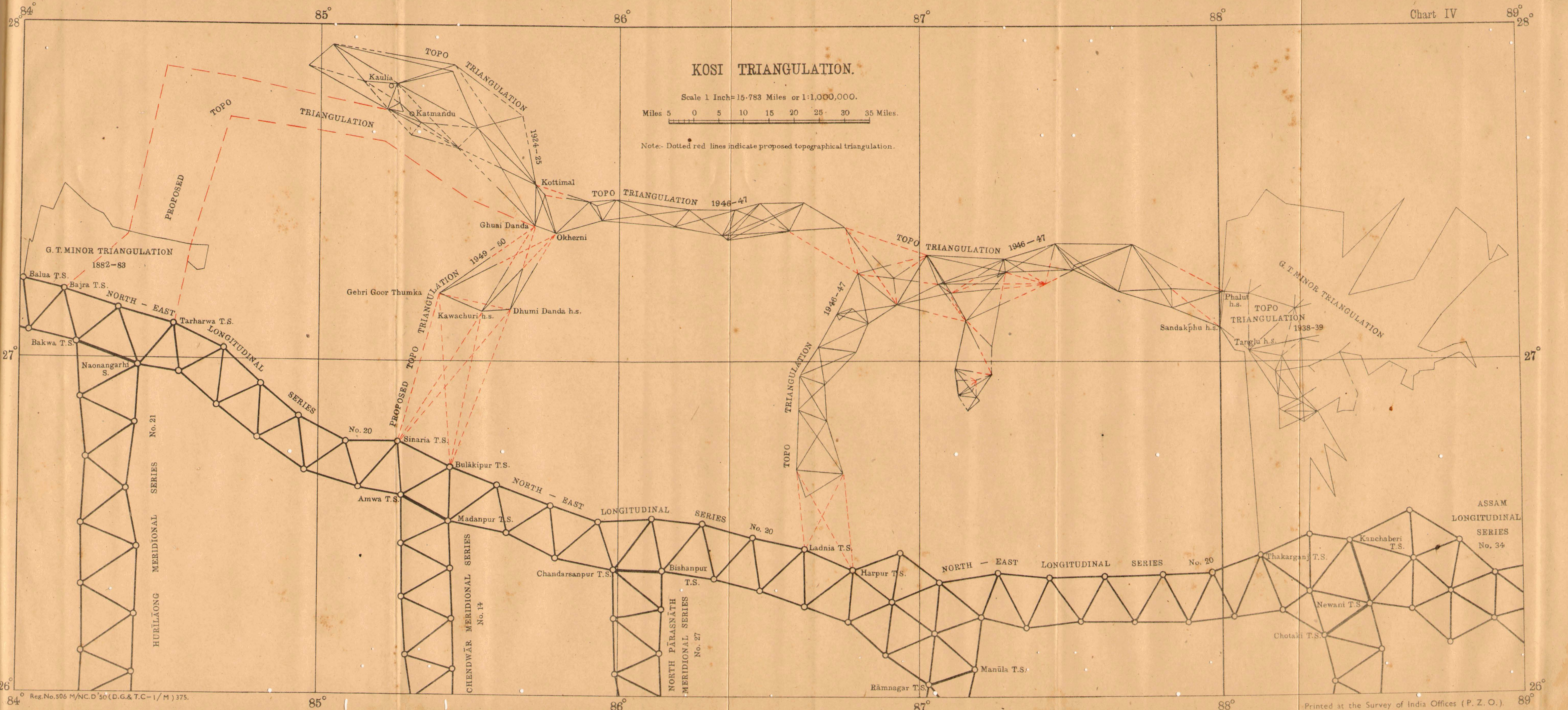
Chart IV
KOSI TRIANGULATION.
Scale 1 Inch=15·783 Miles or 1:1,000,000.
Miles 5 0 5 10 15 20 25 30 35 Miles.
Note:- Dotted red lines indicate proposed topographical triangulation.
TOPO TRIANGULATION 1924-25
Kaulia
Katmandu
TOPO TRIANGULATION
PROPOSED
Kottimal
TOPO TRIANGULATION 1946-47
Ghuai Danda
Okherni
TOPO TRIANGULATION 1949-50
Gebri Goor Thumka
Kawachuri h.s.
Dhumi Danda h.s.
PROPOSED TOPO TRIANGULATION
TOPO TRIANGULATION 1946-47
TOPO TRIANGULATION 1946-47
G. T. MINOR TRIANGULATION 1882-83
Balua T.S.
Bajra T.S.
NORTH-EAST LONGITUDINAL SERIES No. 20
Tarharwa T.S.
Bakwa T.S.
Naonangarhi S.
Sinaria T.S.
Bulākipur T.S.
Amwa T.S.
Madanpur T.S.
Chandarsanpur T.S.
Bishanpur T.S.
Ladnia T.S.
Harpur T.S.
Rāmnagar T.S.
Manūla T.S.
HURILĀONG MERIDIONAL SERIES No. 21
CHENDWĀR MERIDIONAL SERIES No. 14
NORTH PĀRASNĀTH MERIDIONAL SERIES No. 27
TOPO TRIANGULATION
Phalut h.s.
Sandakphu h.s.
TOPO TRIANGULATION 1938-39
Tanglu h.s.
G. T. MINOR TRIANGULATION
Thakarganj T.S.
Kanchaberi T.S.
Newani T.S.
Chotaki T.S.
ASSAM LONGITUDINAL SERIES No. 34
84° 85° 86° 87° 88° 89°
28° 27° 26°
Reg. No. 506 M/NC.D'50 (D.G.& T.C-1/M) 375.
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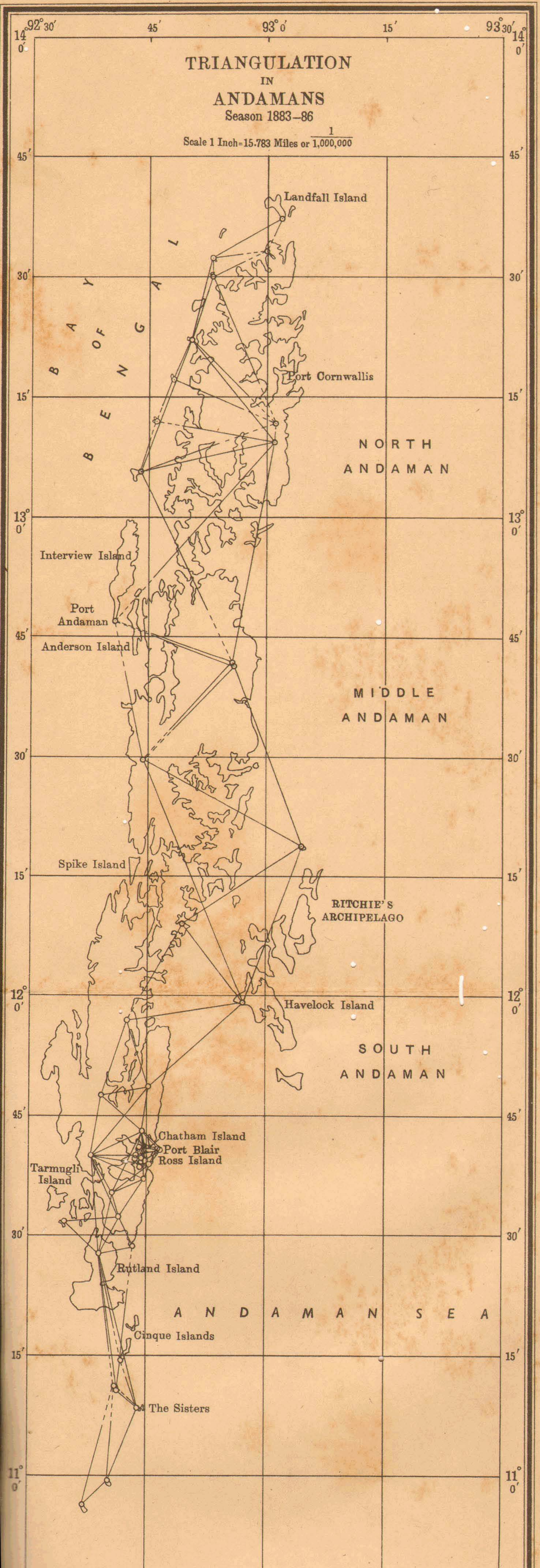


TRIANGULATION
IN
ANDAMANS
Season 1883-86
Scale 1 Inch=15.783 Miles or 1/1,000,000
92° 30′
45′
93° 0′
15′
93° 30′
14° 0′
13° 0′
12° 0′
11° 0′
30′
15′
BAY OF BENGAL
Landfall Island
Port Cornwallis
NORTH ANDAMAN
Interview Island
Port Andaman
Anderson Island
MIDDLE ANDAMAN
Spike Island
RITCHIE'S ARCHIPELAGO
Havelock Island
SOUTH ANDAMAN
Chatham Island
Port Blair
Ross Island
Tarmugli Island
Rutland Island
ANDAMAN SEA
Cinque Islands
The Sisters

their coefficients of expansion determined or applied to base-line measurements.

An astronomical azimuth was determined at the site of the observatory in 1884 and the heights of the triangulation are based on Ross Bench-Mark C which was connected by levelling to a tide-gauge. The tide-gauge observatory at Port Blair was in operation from 1880 to 1905. Mean sea-level as determined from 1880–86 observations worked out to be 4·708 feet above zero of the gauge. This figure makes Ross' B.M. 7·766 ft. above M.S.L. and for the purpose of triangulation heights, the spirit levelled height of this B.M. was defined as 7.77 ft.

Later on, an improved value of M.S.L. was derived from 25 yearly means (1880–1905), which made Ross' B.M. to be 7.71 ft. above M.S.L. but this value has not been brought into use.

Although the angles were measured with considerable care with a 10-inch theodolite, the average triangular error is rather large (about 8 seconds). Some of the triangles are not well conditioned on account of the peculiar shape of the Islands and the intersected points are particularly weak. The work was executed under difficult conditions as except in the vicinity of Port Blair, the islands are covered with dense vegetation.

(*b*) *Nicobar Islands*.—During the course of triangulation in the Andaman Islands, the Government of India decided to make an accurate survey of the coast-line of the Nicobar Islands as well and to determine the position of various conspicuous hills in the interior to enable the navigators to use them as landmarks. In pursuance of this decision, triangulation in the Nicobar Islands was carried out in 1886–87. For this purpose, a base-line about 1,000 yards long was measured in the Camorta Settlements with 10-foot seasoned teak wood rods of 3-inch cross-section standardized against an iron bar supplied by the G.T. Survey Office at Dehra Dūn, as for bases measured in the Andamans, and a small observatory was built near the Police Lines there to serve as the origin of the survey.

The latitude of the observatory was determined by 88 circum-meridian altitudes.

The longitude was determined differentially from that of Ross Bench-Mark C, (Chatham Island, Port Blair), by transfer of chronometers. Eight chronometers were carried 3 times between the two stations. The longitude of the Chatham Island observatory had been determined in 1861 by Mr. Nicholson of the Survey of India.

An azimuth was measured at Camorta observatory by observing a circumpolar star near elongation.

The instrument used for the determination of the latitude and azimuth was a 14-inch theodolite by Troughton and Simms.

The triangulation is based on the following elements :—

(i) Camorta observatory (1886–88 values) :
Latitude 8° 2′ 20″·79 N.
Longitude 93° 31′ 55″·05 E.

(ii) Azimuth of signalling staff—146° 33′ 00″.

(iii) Height above mean sea-level of the upper surface of bench-mark built near the jetty at Camorta—6 feet. This height has been obtained from a tidal record extending over one month.

(iv) Length of the base-line—2994·653 feet.

(v) Everest's elements for the earth, as used in the Survey of India.

The triangulation was executed under the supervision of Lieut.-Colonel G. Strahan, R.E., with 14-inch and 6-inch theodolites by Troughton and Simms. The average triangular error was 10″·9.

A second base-line was measured on the north coast of the Great Nicobar. An azimuth was also observed to Polaris near elongation. By this means the breadth of the channel between the Great and Little Nicobars was determined and further some conspicuous hill-tops in the latter island were fixed which were also intersected from the stations on the islands of Katchall and Trinkat, whereby the triangulation was carried through the Little Nicobar to the Great Nicobar.

The coast-line traverses were worked out by the Subtense Bar method.

Several of the stations of the triangulation and also some of those at which the latitude was observed, were below the high water mark. Consequently no permanent marks were built there.

(c) *Existing data and charts of the Andaman and Nicobar Islands.*—Great confusion exists about the terms of reference of the printed data and charts of these Islands, and this led to a considerable amount of embarrassment in World War II. For the Nicobar Islands, the following frames of reference are available :—

(i) Survey of India spherical data triangulation pamphlet (1927).

(ii) Survey of India ½-inch sheet (Nicobars), 1887.

(iii) Survey of India grid pamphlet (1944).

(iv) Admiralty Chart 1153 (scale 1 inch = 1 mile), containing Nancowry, Trinkat, Camorta and Katchall Islands.

(v) Admiralty Chart 840 (scale 1 inch = 6 miles), containing the above Islands and also Tillanchong, Teressa and Car Nicobar.

(vi) South Asia Series (Andaman), scale 1/2M, 1915.

As has already been stated, the original survey of 1886–88 of the Nicobar Islands was based on Camorta observatory as origin, its longitude being determined with reference to a point in Port Blair by the method of transport of chronometers. The longitude of Port Blair had been determined in 1862 with reference to Greenwich directly from lunar culminations.

It was later realized that this was an inaccurate method. Accordingly in 1899, another determination of longitude of Port Blair was made with respect to a G.T. point in Burma (Diamond Island, Flagstaff) by transport of chronometers. This value differed from the preceding one by 1′ 16″. Hence the longitude of Camorta and points in the Nicobars based on it require a correction of +1′ 16″. In the following discussion, the longitudes dependent on 1862 values of Port Blair will be called unadjusted values, and those based on 1899 values as adjusted values.

Items (ii) and (v) mentioned above are based on unadjusted values, while (i) is on adjusted values. The two Admiralty Charts (iv) and (v) appear to have been prepared independently of each other. Chart 840, the older one of the two is ungridded and was compiled from surveys and observations of Frigate "Novarro" in 1858 ; coast-line and topography being carried out in 1887 by the Survey of India after the triangulation of the Island. This chart is in unadjusted terms. Chart 1153 was prepared by the Marine Survey in 1921 and they complicated the situation by introducing yet another value of longitude. They determined the longitude of a new station, Ray Point from Port Blair (whose longitude was supposed to be in terms of the geodetic longitude of Madras) and connected this station to Indian triangulation and found the following difference :—

Admiralty — G.T. (adjusted) = —1″·5 in latitude and —21″·7 in longitude.

No corrections were applied to Marine Survey values to bring them in terms of Indian G.T. values.

The next stage was that the Admiralty Charts were prepared in spherical terms in 1924–25. By wrong reasoning, the value of longitude of Ray Point was decreased by 5″·6, as it was considered that this would make the astronomical longitude of Madras the basis of longitudes, which would be more appropriate.

At the time of gridding the charts at a later date, it was considered that the above procedure was not justified and that for grid the basis of longitude should be restored to that of the geodetic longitude of Madras. This was achieved by making the grid out of sympathy with the graticule by 5″·6 or 186 yards.

Actually the whole confusion was due to faulty assessment of the problems involved and of the methods employed. The method of transport of chronometers is out-of-date and may give an error of 1 mile due to the uncertainty of the rates of the chronometers: and this method only gives the difference of astronomical longitudes. One cannot therefore say that the longitude of Ray Point is in terms of the geodetic longitude of Madras. Until there is a triangulation connection between India and the Nicobars, the latter can only be regarded as being in independent terms.

Due to the above causes, the two versions (spherical and grid) of Chart 1153 are out of sympathy by $5''\cdot 6$; the two charts 840 and 1153 are out of sympathy by 1,700 yards and the Survey of India 1944 grid pamphlet differs from Chart 840 by 1,700 yards.

To get over the confusion until the time that further work is undertaken the Survey of India, 1927 spherical pamphlet which is in adjusted terms must be regarded as the final authority. All others must be reduced to it. This involves the correction of the spherical graticule on Chart 1153 by $+28''\cdot 3$ in longitude and the grid on it by +720 yards in Easting. The graticule of Chart 840 needs shifting by $1'\ 16''$, but the relative positions of all the Islands are correct.

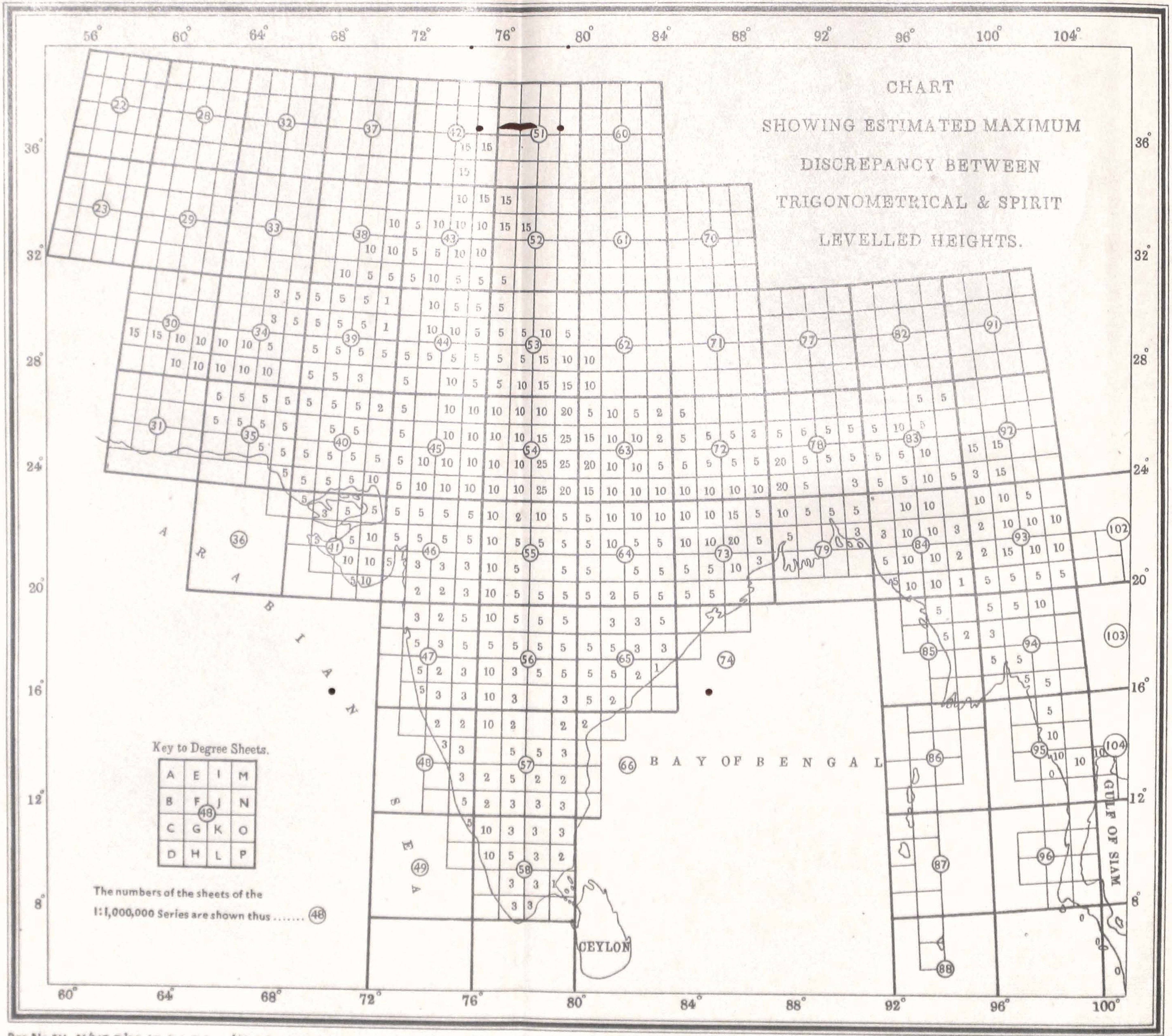
All this produced considerable delays and puzzled the users of the data in World War II. In 1944, the Director of Military Surveys prepared maps on scale 2 inches = 1 mile of Teressa, Car Nicobar and Tillanchong and other islands from aerial photographs.

The maps of Teressa, Car Nicobar and Tillanchong were based on Chart 840 and those of Nancowry, Trinkat, Camorta and Katchall on Chart 1153 without bringing charts 840 and 1153 to the same terms. The new sets of maps of these islands were consequently not in sympathy and the army was at a loss as to how to reconcile them. When the war ended, these maps went in oblivion.

It will be apparent from the above that the existing triangulations both in the Andamans and in the Nicobars are not connected to the Indian Triangulation and are only weakly connected to each other. The base measurements were made with rather crude instruments and the layout of the triangulation is not very good. The longitudes were necessarily determined by the older inaccurate methods of lunar culminations and transport of chronometers. The existing data is in such a tangle that none but an expert can understand the conflicting longitude changes which were applied from time to time.

For any new mapping that may have to be done in this area, new bases and new values of astronomical longitudes determined by the latest methods employing radio signals are the first essential. These would put the islands on their own datums independent of India. There is then the much wider question of connecting the triangulation of these Islands with India to get the geographic co-ordinates in the same terms.

Some years ago, this would have been considéred of academic interest only, as the relative accuracy of points within the borders of each country was all that was considered important. The discrepancies which inevitably exist between the triangulation systems of the different countries because of their being on independent



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Scale $\frac{1}{22,500,000}$ or 1·013 Inches to 360 Miles.

Miles 100 50 0 100 200 300 400 500 Miles.

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datums and different figures of the earth are, however, now-a-days causing embarrassment to mariners, and there is a strong demand for unification of the geographical grids of the world. Modern electronic aids to navigation such as Shoran, Loran, Decca, etc., which have been invented in the last few years have brought to the fore the need for more accurate geodetic data for the preparation of marine charts covering large parts of the globe and containing coast-lines of several countries.

6. **Error in Heights fixed by Geodetic Triangulation.**—Chart VI shows the estimated maximum discrepancy between trigonometrical and spirit-levelled heights of G.T. stations. It will be noticed that the heights of some of the older series are seriously in error. This will also be manifest from the values of *p* (which is an index of precision of trigonometrical heights) as tabulated in Chart I. The error in the height of G.T. series is carried forward when topographical triangulation is based on it and is continued over long distances. This error combined with the accumulation of error in the topographical triangulation can sometimes assume serious proportions. This is best illustrated by the following example.

In December 1944, Lieut. Gadd of the U.S.A. 653 Engineers Corps did some survey work near Jiwani aerodrome (SW. Baluchistān). He pointed out that his heights which were based on sea-level, differed from the Survey of India heights on maps by as much as 30 to 40 feet.

To investigate this discrepancy No. 20 (Cantonment) Party of the Survey of India which was working in the area at that time effected a direct connection of Ganz h.s., one of the stations of the topographical triangulation, to sea-level by spirit-levelling. The sea-level was observed near (within an hour) high and low water. Mr. Wimbush of the Imperial Airways had also established a bench-mark in this area in 1940 and his observations were confirmed by the results of No. 20 Party's work.

It is thus established that the topographical triangulation in this area which is some 300 miles away from the geodetic triangulation, had, in fact accumulated an error of about 30 feet in height, one third of which at least was possibly due to the error in the heights of geodetic triangulation. There is thus need for a systematic examination of all such areas and the improvement of the accuracy of trigonometrical heights by more frequent connections to spirit-levelling lines.

7. **Upkeep of G.T. Stations.**—All geodetic, some minor stations and selected primary bench-marks are under the custody of local officials, who are responsible for their upkeep. Annual reports on their condition are submitted by District officials to the President, Geodetic and Research Branch together with an estimate of the cost of such repairs as may be necessary. Such stations are termed protected.

The stations of geodetic triangulation are generally marked by a circle and dot cut on rock or a loose stone. Above the mark in hilly country is built a low pillar of stone or bricks, and the whole is surrounded by a large platform of loose stones and covered by a cairn, and in flat country a high brick tower. Most of these stations were built over a century ago.

In jungle areas the stations are liable to be destroyed by wild animals and vegetation and in other areas from wind, rain and other natural causes. In some areas, especially Burma, many stations have been dug up by treasure seekers. The result is that rapid decrease is taking place in the number of pairs of stations which can give a value of scale and azimuth to geodetic accuracy for future extensions. This fact came home when data of geodetic triangulation was recently examined for issue and to establish control points from it for the purpose of running triangulation and traverses to fix boundary pillars that are likely to be built to demarcate the boundary between East and West Bengal.

It appears that the time has now arrived to organize a field detachment to visit old stations and replace their structures by monuments of more modern types and to refix their positions with geodetic accuracy where they are completely destroyed and cannot now be identified.

8. **International Geographical Grid of the World.**—It has been pointed out in Technical Report 1947, Part III, Chapter I, page 33, para 22, that the triangulation of India and Burma is computed on the Everest spheroid, the axes of which are about 3,000 feet smaller than most modern spheroids and which is not in good agreement with the geoid. Moreover the deviations of the vertical accepted at the datum of Indian geodetic triangulation, viz., Kaliānpur are not defined on an International basis. The Survey of India would therefore welcome any scheme which would make for uniformity in this respect in all the countries of the world.

Recently the International Hydrographic Bureau has been evincing some interest in the unification of the Geographical Grids of the World. At present discrepancies occur between the triangulation systems of the various nations, firstly due to importance having been attached to relative accuracy of the stations within the borders of each country and secondly due to the use of different figures of the earth for the computation of these triangulation systems.

With the introduction of modern electronic aids to navigation such as Shoran, Loran, Decca, etc., there is need for more accurate geodetic data for the preparation of marine charts which contain coasts of several countries and cover large parts of the globe. The Fifth International Hydrographic Conference held at Monte-Carlo in 1947 therefore passed a resolution recommending that the Directing Committee of the International Hydrographic Bureau should get in touch with the International Union of Geodesy and Geophysics for the purpose of finding the best means of making and reducing observations for obtaining the absolute geographic co-ordinates of points on the globe with the highest possible standard of accuracy.

The Survey of India will naturally watch the outcome of these efforts with interest and would be willing to offer all the co-operation it can.

It is also of great interest to learn that the Italian Military Geographic Institute has initiated action for the simultaneous adjustment of the European Geodetic Nets of Triangulation. India has always been interested in a connection of the Indian Triangulation system to that of Europe and as pointed out in the last years' Technical Report, the chances of such a connection in the near future are now better and consequently the adjustment of the geodetic triangulation nets of Europe is regarded as of great importance.

Chapter II

LEVELLING

by B. L. Gulatee, M.A. (Cantab.)

Section I—Field Season 1947–48

9. **General.**—Due to the paucity of trained personnel only two single levelling detachments could be organized. One of these detachments under Mr. I. M. Saklani completed the back levelling of the High Precision line from Bombay to Ratnāgiri which was levelled in the fore direction only during the last field season. Another detachment under Mr. B. P. Rundev (Surveyor) carried out precision levelling in the fore direction from Burdwān to Diamond Harbour. The back levelling of this line was carried out during the same season by Mr. H. C. Gupta (Surveyor) as the results were urgently required by the River Surveyor to the Commissioners for the Port of Calcutta. In addition to the above, revisionary levelling from Roorkee to Hardwār was carried out with a view to detect changes of level in this area. A detachment also carried out double tertiary levelling for the G.I.P. railway.

10. **Summary of out-turn.**—The total out-turn of work (see Table 1) carried out during field season 1947–48 is as follows :—

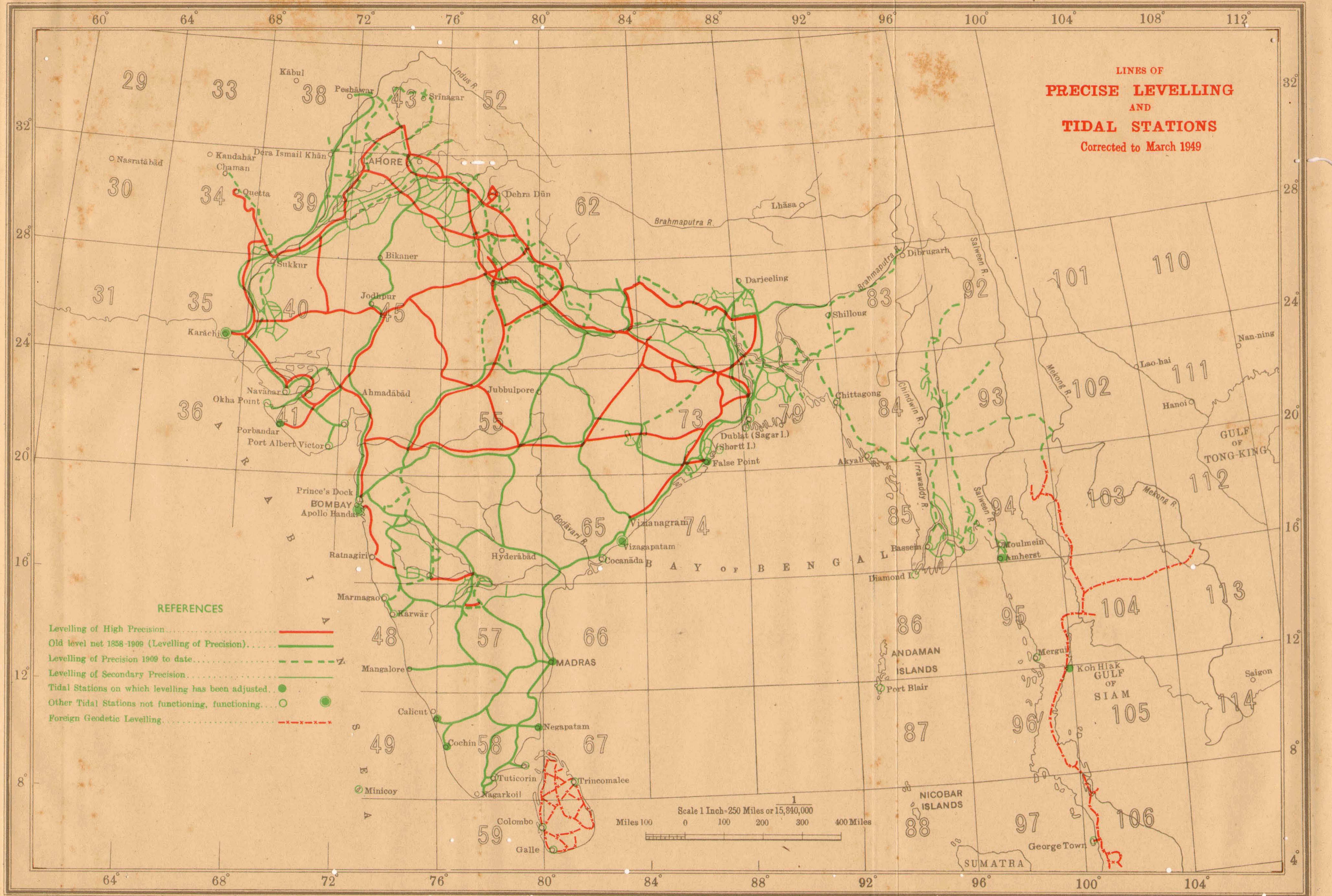
(*a*) High Precision Levelling in one direction .. .. .. 239 miles (251 gross)

(*b*) Levelling of Precision in both directions .. .. .. 131 miles (142 gross)

(*c*) Levelling of Precision in one direction 22 miles

(*d*) Double tertiary levelling .. 21 miles

11. **Ratnāgiri to Bombay.**—A detachment under Mr. I. M. Saklani with one recorder and 15 *khalāsīs* commenced work at Ratnāgiri on 6th December 1947 from Standard Bench-mark (Type M) in the compound of the Collector's bungalow. The route followed was the same by which the fore-leveller had gone in the previous season (see Technical Report 1947, Part III, para 27, pages 36 and 37). For transport a 3-ton lorry was secured on contract from Messrs. R. B. Shirke Bros. of Ratnāgiri at Rs. 20/- per day, which included all charges such as the pay of the driver and cleaner, repairs and maintenance, except the cost of petrol which was supplied by the detachment. The lorry functioned satisfactorily and the programme was completed in good time. The work was closed on Standard Bench-mark No. 2/47 B at Bombay on 22nd April 1948 and the detachment returned to Dehra Dūn for recess.



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The health of the detachment remained generally good except that the recorder fell sick on 21st January 1948 and had to be replaced by a computer from Dehra Dūn. The work in the meantime was continued single handed by the observer for about 20 days. One *khalāsi* died of an attack of paralysis.

12. **Burdwān to Diamond Harbour.**—In August 1947, the River Surveyor to the Commissioners for the Port of Calcutta pointed out that levelling carried out by him showed that bench-mark No. 159/79 B at Diamond Harbour had sunk by about 6 inches relative to bench-mark No. 160/79 B in the same locality. He, therefore, made an urgent request to this department to confirm this subsidence. A detachment under Mr. B. P. Rundev (Surveyor), with one recorder and 14 *khalāsīs* left Dehra Dūn on 20th December 1947 and commenced work at Diamond Harbour on 27th December 1947 from B.M. No. 91/79 B and closed on B.M. No. 353/79 B at Calcutta. Besides confirming the subsidence of B.M. 159/79 B relative to B.M. 160/79 B referred to above, this levelling also provided reference bench-marks for the river gauges along the Hooghly river.

There is, however, no rock-cut bench-mark near Calcutta and it was considered advisable to continue the levelling to a stable bench-mark. The levelling was, therefore, carried on further from Calcutta (B.M. No. 353/79 B) to Burdwān (B.M. No. 116/73 M). This served another useful purpose too. The previous levelling line from Calcutta to Burdwān ran along the main road. During World War II this road was widened considerably by the Americans and all the bench-marks were obliterated. Sixty-nine new bench-marks have now been constructed along this road.

The levelling in the back direction was carried out by Mr. H. C. Gupta (Surveyor) in the same season. He replaced Mr. B. P. Rundev on 24th February 1948 and commenced work on 26th February 1948 at Burdwān from B.M. No. 116/73 M and following the route of the fore leveller closed work on B.M. No. 91/79 B at Diamond Harbour on 25th April 1948. Results of this levelling are discussed in Chapter VIII, Research and Technical Notes.

At the request of the River Surveyor, the levelling from Calcutta to Diamond Harbour has been extended to Dublat and work is in progress to relevel the line from Howrah to Balasore via Hijli. This is described in Section II of this Chapter.

13. **Upwarping of Siwālik axis.**—A line of precise levelling (No. 61 B) was run from Nojli to Hardwār in 1908, which connected several bench-marks built by the Irrigation Department of the U.P. along the route from Roorkee to Hardwār (Chart VIII). This line runs through the gap in the Siwālik range carved by the river Ganges. The Siwālik range is of recent origin and the intention was to relevel this line at frequent intervals to detect the upward movement of the Siwālik axis which is of considerable geological interest. This objective appears to have been forgotten in the course of time

and most of the fine bench-marks built by the Irrigation Department have not been preserved intact and have been disturbed by routine repairs carried out by the same department. A revision of this line was carried out in November, 1947 by Mr. Jagan Nath (Surveyor) assisted by Mr. H. C. Gupta (Surveyor) and 15 *khalāsis*.

The results are given in Table 3. In this table a comparison is made of the observed heights above the Standard Bench-mark at Roorkee, as derived by the old (1908) and new (1947) levelling, of eleven bench-marks which appeared to have remained undisturbed. The figures in column 6 are very interesting, as they are all of the same sign. That they are significant would be apparent from a comparison with the values in column 7, which gives their probable errors. It is thus evident that a general rise of about one inch in 40 years appears to have occurred in this area.

There were two handicaps in the above work—one was that there is no stable bench-mark at Hardwār similar to the one at Roorkee, on which the levelling line from Roorkee could be closed with confidence and the second was that the marks were mainly on milestones which are subject to frequent tampering by the Public Works Department.

At Hardwār a standard bench-mark (Type M) has since been built. In addition it is proposed to build interred bench-marks (Type B) at Bājūheri, Dhanauri, Rānipur, Jwālāpur and Hardwār railway station (see Chart VIII) and to preserve them. It is also proposed to extend this levelling line to Rāiwāla and Rishikesh. Levelling will then be undertaken at 5-yearly intervals and it is hoped that they will provide quantitative results as regards rise of the Siwālik axis.

14. **Changes of Level across Krol Thrust.**—It is also proposed during the next field season to build some bench-marks along some major faults and thrust planes suggested by the Geological Survey of India and to connect them by precise levelling. One such area is that of the Krol Thrust shown in Chart IX, where levelling bench-marks are being established at points 3404 and 3285 lying on the Siwālik block and points 2993 and 3089 on Kalanga Hill, which belongs to the pre-tertiary overthrust Krol unit. Periodic levelling for connecting these bench-marks may be of great geological significance.

15. **Tertiary levelling from Ghoradongri to Pathakhera.**—This levelling was carried out at the request of the Chief Engineer G.I.P. railway to provide the heights of three bench-marks established at Ghoradongri railway station, Salaiya and Sarni during March to April 1948. Observations were commenced by Mr. S. N. Nandi (Surveyor) from Shahpur—B.M. 25/55 F of line 115. The work was carried out on the system of fore and back levelling. The back levelling was commenced immediately on the conclusion of the fore levelling. Check levelling was carried out from B.M. 36/55 F to B.M. 25/55 F on the same system.

LEVELLING LINE 61 B NOJLI TO HARDWAR

(Portion Roorkee-Hardwar)

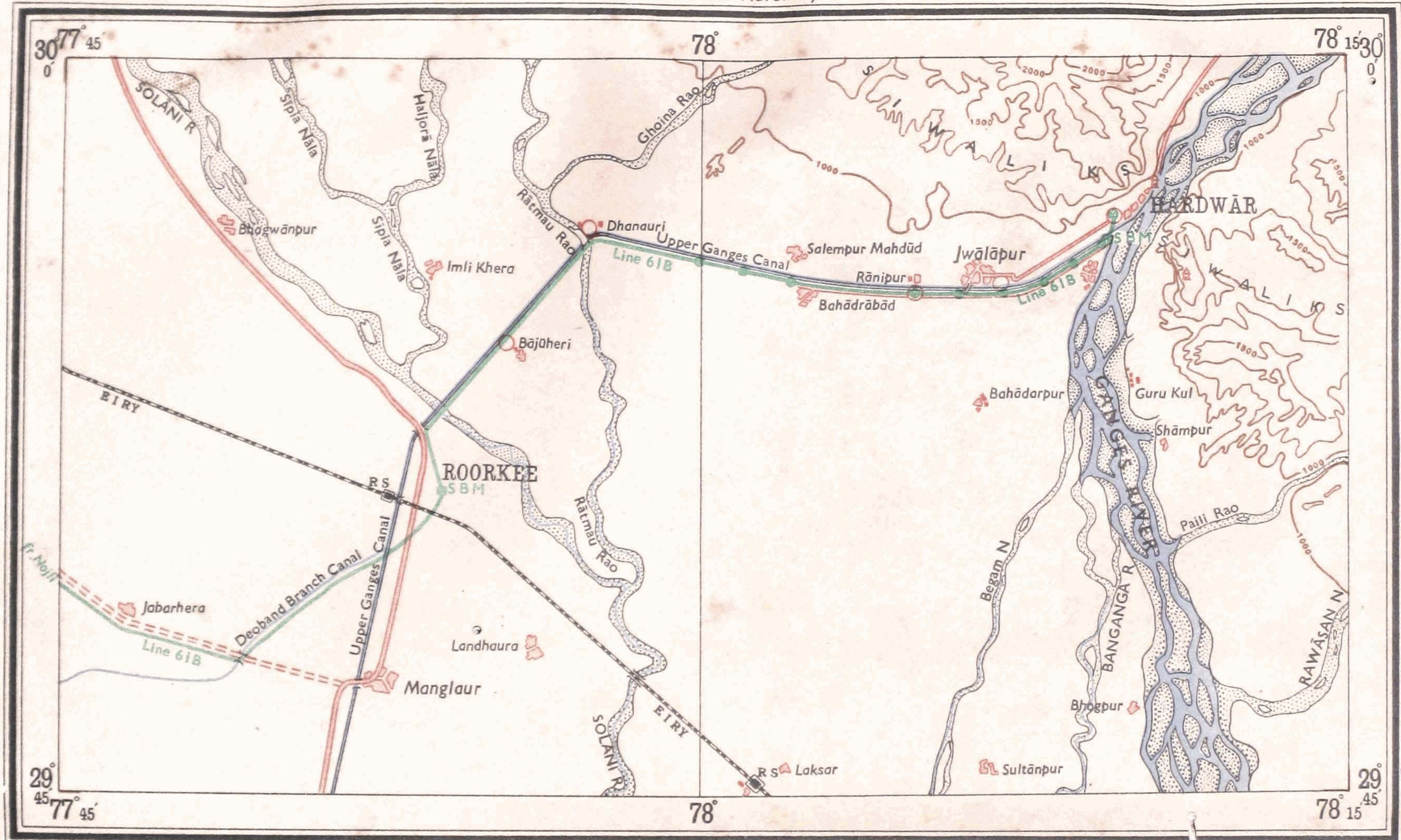

Chart VIII

REFERENCES

Levelling Line with number .... Line 61 B

Old bench marks ....

New bench marks (type B) ....

Standard bench marks ....

Scale 1 Inch to 4 Miles, or 1:253,440.

Miles 5 4 3 2 1 0 5 Miles

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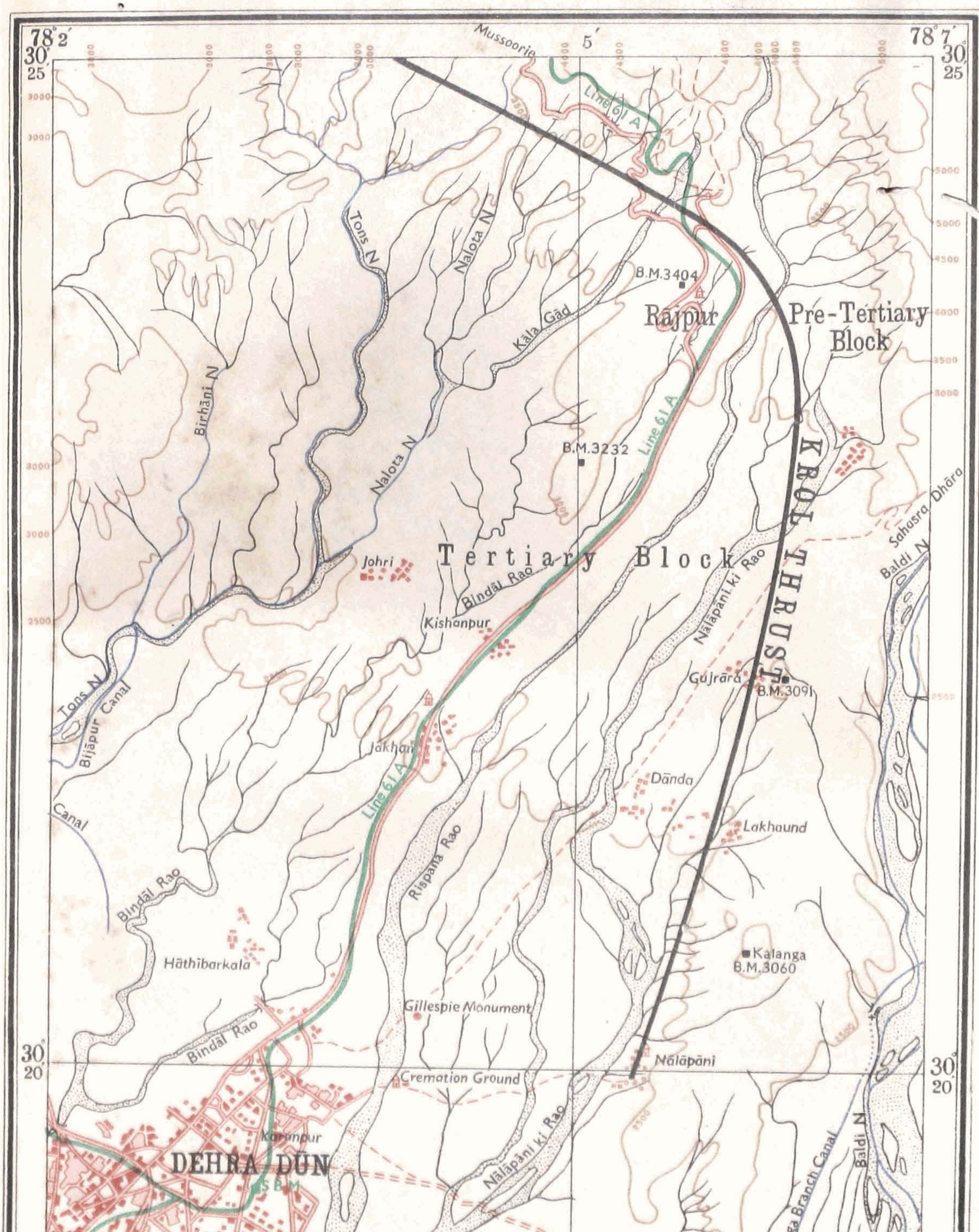
KROL THRUST

Chart IX



Reg. No 490 M/NC '49-375

Printed at the Survey of India Offices, (P. Z. O.).

Scale 1 Inch to a Mile or 1:63,360.

Furlongs 8 6 4 2 0 1 Mile

SECTION II—FIELD SEASON 1948–49

16. **General.**—During this field season, only two detachments were provided for in the first instance but three more were raised later to meet urgent demands from extra-departmental authorities.

Detachment No. 1 completed levelling in the back direction of the High Precision line Kolhāpur to Ratnāgiri, which was levelled in the fore direction during the field season 1946–47. It then carried out high precision levelling in the fore direction from Kolhāpur to Hubli via Belgaum and Dhārwār, and from Hubli to Kārwār via Yellapur.

Detachment No. 2 was employed on levelling of high precision from Raipur to Vizagapatam via Dhamatri, Jeypore, and Vizianagram in the fore direction.

Detachment No. 3 was organized at the request of the River Surveyor to the Commissioners for the Port of Calcutta to run a line of high precision levelling in both fore and back directions from Diamond Harbour to Dublat. After completing this work, the detachment carried out about 160 miles of high precision levelling from Howrah to Jellasore.

Two more levelling detachments were organized for precise levelling from Hoshangābād to Mhow for the Executive Engineer Lower Narbada Division in connection with the Narbada and Tāpti Projects.

17. **Summary of out-turn.**—The total out-turn of levelling (see Table 1) for field season 1948–49 is as follows :—

(*a*) H.P. Levelling in one direction .. 856 miles (939 gross)

(*b*) H.P. Levelling in both directions .. 54 miles (56 gross)

(*c*) Simultaneous double levelling of Precision in both directions .. 201 miles (236 gross)

18. **Kolhāpur to Ratnāgiri.**—Levelling detachment No. 1 under Mr. I. M. Saklani with one recorder and 15 *khalāsīs* commenced High Precision levelling at Kolhāpur on 23rd October 1948 from B.M. No. 23/47 L and closed on B.M. No. 1/48 J at Kārwār on 2nd April 1949. The route followed was the same by which the fore leveller had gone in season 1946–47, that is via Malkāpur, Amba Ghāt, Sakarpa and Pali. The steep hills along the route were crossed at Amba Ghāt. The bench-marks en route from Hathkhamba to Ratnāgiri were identical with those of this section of line No. 122 and consequently the work was closed on a rock-cut bench-mark at Hathkhamba.

After completion of Kolhāpur–Ratnāgiri section, the detachment returned to Kolhāpur and recommenced work in the fore direction from B.M. No. 23/47 L on line No. 129 of the new level net from Kolhāpur to Mangalore. It was run via Kagal, Sankeshwar, Belgaum, Kittur and Dhārwār and closed on B.M. No. 1/48 M at Hubli. From this bench-mark a branch-line was run via Yellapur to B.M. No. 1/48 J at Kārwār. The route followed from Kolhāpur to Hubli was along the old line No. 29 and that from Hubli to Kārwār along the old line No. 17. All old bench-marks which could be traced and found intact were connected including bench-mark No. 1/48 J which was the bench-mark of reference of the old tidal observatory at Kārwār now closed. The difference between old and new values of these bench-marks are being studied and will be discussed in the next Report.

New standard bench-marks (Type M) at Kolhāpur, Hubli and Kārwār and four other types of primary protected bench-marks were connected during the work. Levelling was also carried to three G.T. stations and four hill stations of topographical triangulation. The whole work covered 16,522 feet of rise and 18,696 feet of fall.

For transport a 3-ton lorry was engaged from Messrs. R. B. Shirke Bros. of Ratnāgiri at Rs. 23/- per day inclusive of all charges except petrol. It greatly helped in speeding up the work through the Western Ghāts and other such areas where transport difficulties would otherwise have made progress very slow.

The general health of the detachment remained good throughout, though part of the line ran through a notoriously malarious area.

19. Raipur to Vizagapatam.—Detachment No. 2 under Mr. H. C. Gupta (Surveyor), with one recorder and 15 *khalāsīs* first took up the levelling in the fore direction of the High Precision line from Raipur to Vizianagram. He commenced work on 23rd October 1948, and starting from Standard Bench-mark No. 173/64 G (Type P) at Raipur continued via Dhamtari, Sihāwa, Raigarh, Jeypore and Salur to Vizianagram, and closed the line on Standard Bench-mark No. 237/65 M (Type M) at P.W.D. Inspection Bungalow, Vizianagram.

Thereafter he started work on the section Vizianagram to Vizagapatam and completed it on 18th April 1949. This section closes on Standard Bench-mark No. 91/65 O (Type P) at Vizagapatam, which is also the reference bench-mark for the tidal observatory there. The route followed was the same as that for the old line No. 36.

The line from Raipur to Vizagapatam runs partly through cultivated plain area and partly through thick forest.

For transport, bullock carts were used on a permanent basis wherever possible. The local officials were generally helpful, but rations were obtainable with great difficulty particularly in Madras Presidency. Much inconvenience was experienced due to dearth of post offices enroute, particularly on the portion from Dhamtari (C.P.) to Nowrangapur (Orissa) where the existing post offices are about 50 to 60 miles apart and the telegraph offices are still fewer being about 150 miles apart.

As many old bench-marks as could be traced along the route of work were connected. A new Standard Bench-mark (Type M) at Rudri and seven other types of primary protected bench-marks were also connected. Thirteen hill stations of geodetic and topographical triangulation were connected to spirit levelling during the course of the work.

The whole line from Raipur to Vizagapatam covered 15,577 feet of rise and 13,457 feet of fall.

20. Diamond Harbour to Dublat and Howrah to Balasore.—No. 3 levelling detachment under Mr. B. P. Rundev (Surveyor) with one recorder and 14 class IV servants commenced fore levelling from B.M. No. 91/79 B at P.W.D. Inspection Bungalow, Diamond Harbour on 3rd January 1949. After satisfactory check-levelling of old bench-marks including those connected in the previous season, the work was carried on along old line 74 B via Sagar and closed on a newly inscribed bench-mark on top of pier at Dublat as near as possible to the old site of the tidal observatory, since none of the old marks were found existing. A number of bench-marks were left in the neighbourhood of this inscribed bench-mark. The work was thereafter continued in the back direction along the same route by which the fore levelling was brought and the line was finally closed on B.M. No. 91/79 B at Diamond Harbour on 27th February 1949. All the old bench-marks found en route were connected during fore and back levelling of the line Diamond Harbour to Dublat. The results have not been analysed yet and will be discussed in the next Report.

After completion of the line from Diamond Harbour to Dublat the work was restarted from B.M. No. 353/79 B at Calcutta on 1st March 1949 and carried on along old line No. 75 in the fore direction via Ulubāria, Kedgeree, Nijkasba (Hijli) and Contai towards Balasore covering about 60 miles till 31st March 1949. The work was closed at Jaleswar (Jellasore) on 20th May 1949. Eventually it will be of interest to carry the levelling to False Point to provide an independent connection to mean sea-level.

This work was partly paid for by the Commissioners for the Port of Calcutta. The lines run were in the nature of revision levelling of old line No. 74 B, Diamond Harbour to Dublat, and part of old lines Nos. 75 and 121, Howrah to Balasore. The results are being worked out and it is hoped that they would provide very useful information regarding the amount of changes of level, subsidence or otherwise, in this area.

21. Hoshangābād to Mhow.—Two levelling detachments were organized at short notice to meet the requirements of the Executive Engineer, Lower Narbada Division for the Narbada and Tapti projects. It was a paid for job and in order to execute it as early as possible, the line from Hoshangābād to Mhow was divided into two portions. Detachment 'A' under Mr. A. K. Bhattacharjee (Officer Surveyor) assisted by Mr. S. N. Nandi (Surveyor) with 15 *khalāsīs* commenced work on the portion Hoshangābād to Khandwa from B.M. No. 87/55 F at Hoshangābād on 21st January 1949 and after check-levelling at Hoshangābād and again at Itārsi (see Table 2) en route carried it forward towards

Khandwa. Detachment 'B' under the charge of Mr. J. K. Donald (Surveyor) assisted by Mr. V. D. Bhatt (Surveyor) with 14 *khalāsīs* started work simultaneously on the portion Mhow to Khandwa from Standard Bench-mark No. 83/46 N at Mhow on 21st February 1949 and carried it forward towards Khandwa. A junction was effected at a bench-mark near the Kalamachak river on 18th May 1949.

The levelling was carried out both in the fore and back directions by sections of 8 miles, each section being subdivided into 4 sub-sections of 2 miles each. These sub-sections were levelled first by the fore leveller in the morning and in the afternoon till the 8-mile section was completed. The back leveller then followed the same procedure of observations for the 8-mile section from the opposite direction levelling in the afternoon the sections done in the morning by the fore-leveller and vice versa. This was done to ensure that the two observers observed the same sections under different atmospheric conditions.

The maximum discrepancy allowed between the results of fore and back levelling in the main line for each 2-mile sub-section was 0·025 ft. For branch-lines a greater tolerance was allowed. The work as a whole can be classed as simultaneous double levelling of precision.

22. **Probable errors of levelling.**—The probable accidental and systematic errors in levelling of high precision calculated by the usual formulæ are given below :—

Line No.	Name of the line	Probable systematic error per mile	Probable accidental error per mile
		feet	*feet*
Part of Nos. 74 & 74 B	Burdwān to Diamond Harbour via Calcutta	± 0·00202	± 0·00383
Part of No. 74 B	Diamond Harbour to Dublat ..	± 0·00038	± 0·00301
Part of No. 122	Bombay to Ratnāgiri ..	± 0·00109	± 0·00374
Part of No. 127	Ratnāgiri to Kolhāpur ..	± 0·00159	± 0·00450
Maximum error permissible in H.P. Levelling		± 0·00106	± 0·00416

The probable error of the secondary levelling line from Mhow to Hoshangābād is ± 0·00029 feet per mile.

23. **Progress of the New Level Net.**—The levelling under report has added 510 miles of completed levelling (both directions) and about 800 miles in one direction only to the total mileage of the new level net. Chart VII shows that it has not been possible to extend this net into southern India. About 4,700 miles of levelling of a total estimated mileage of 15,800 miles still remains to be carried out and at the present rate of progress it may take another 16 years to complete.

The existing skeleton High Precision level net is not at all sufficient for providing datum bench-marks for secondary and tertiary levelling which is required urgently for the various irrigation and hydro-electric projects. It is hoped to accelerate the progress of precision and secondary levelling in India by employing more personnel and by inducing the provincial governments, railway and other interested agencies to carry out some levellings in their areas according to specified standards of accuracy and tied on to the Survey of India High Precision level net.

TABLE 1.—*Tabular statement of out-turn of work, season 1947–48*

Detachments and lines levelled	Dates	Distance levelled: Main-line	Distance levelled: Extras and branch-lines	Distance levelled: Total	Total: Rises	Total: Falls	Number of stations at which the instruments were set up	Number of bench-marks connected: Protected Primary: Rock-cut	Number of bench-marks connected: Protected Primary: Other	Number of bench-marks connected: Others
		Mls.	*Mls.*	*Mls.*	*feet*	*feet*				
H. P. Levelling Detachment.										
Line No. 122 (Surat to Ratnāgiri) portion Ratnāgiri to Bombay (Back)	Dec. 47 to April 48	239	12	251	10,801	10,630	4,828	3	4	418
Parts of Lines 74 and 74 B (Pirpainti to Howrah & Kidderpore to Dublat) portion Diamond Harbour to Burdwān (Fore)	Dec. 47 to Feb. 48	131	11	142	1,419	1,375	2,146	..	15	223
Do. (Back)	Feb. 48 to April 48	130	11	141	1,456	1,554	2,256	..	15	230
Parts of branch-lines 61 B (Nojli to Hardwar) & 61C (Dehra Dūn to Hardwār) portion Roorkee to Hardwār (Fore)	16-11-47 to 25-11-47	22	..	22	304	207	291	..	1	24
Season 1948–49										
H. P. Levelling Detachment.										
Line No. 127 (Ratnāgiri to Hyderābād Deccan) portion Kolhāpur to Ratnāgiri (Back)	Oct. 48 to Dec. 48	76	4	80	4,643	5,868	1,810	2	12	147
Line No. 129 (Kolhāpur to Mangalore) portion Kolhāpur to Hubli (Fore)	Dec. 48 to Feb. 49	133	9	142	6,948	6,143	2,627	..	27	215

(Continued)

TABLE 1.—*Tabular statement of out-turn of work, season 1948–49.*—(concld.)

Detachments and lines levelled	Dates	Distance levelled: Main-line	Distance levelled: Extras and branch-lines	Distance levelled: Total	Total: Rises	Total: Falls	Number of stations at which the instruments were set up	Number of bench-marks connected: Protected Primary: Rock-cut	Number of bench-marks connected: Protected Primary: Other	Number of bench-marks connected: Others
		Mls.	*Mls.*	*Mls.*	*feet*	*feet*				
Branch Line of Line No. 129 (Kolhāpur to Mangalore) portion Hubli to Kārwār (Fore)	Feb. 49 to April 49	104	14	118	4,931	6,685	2,403	1	18	169
Line No. 124 Raipur to Vizianagram (Fore)	Oct. 48 to April 49	339	41	380	15,122	12,909	7,304	7	29	318
Line No. 126 (Vizianagram to Rajahmundry) portion Vizianagram to Vizagapatam (Fore)	2-4-49 to 18-4-49	46	3	49	455	548	664	2	3	50
Portion of Line 74 B (Kidderpore to Dublat) portion Diamond Harbour to Dublat (Fore)	3-1-49 to 31-1-49	53	3	56	485	496	715	..	2	80
Do. (Back)	1-2-49 to 27-2-49	54	2	56	552	527	804	..	1	77
Line No. 75 (Kendrapāra to Howrah) portion Howrah to Jaleswar (Fore)	1-3-49 to 20-5-49	164	12	176	1,788	1,769	2,398	..	8	254
Secondary Levelling Detachment										
Line Hoshangābād to Mhow	20-2-49 to 30-5-49	201	35	236	2,057	3,832	2,962	..	4	346

TABLE 2.—*Check-levelling*

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling: No.	Degree sheet	Description	Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by: Date of original levelling	Original levelling (published values)	Check-levelling 1947-48	Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1947-48 than when originally levelled
			miles		*feet*	*feet*	*feet*
		At Bombay on lines Nos. 32 & 122					
2	47 B	S.B.M., Bombay ..	0·00	1877-78, 1906-07, 1910-11	0·000	0·000	0·000
3	,,	Step ..	0·08	,,	− 2·173	− 2·169	+0·004
4	,,	Step ..	0·08	,,	− 2·139	− 2·130	+0·009
5	,,	Step ..	0·31	,,	− 3·540	− 3·520	+0·020
6	,,	Step ..	0·31	,,	− 3·458	− 3·438	+0·020
7	,,	Step ..	1·16	,,	− 7·252	− 7·251	+0·001
39	,,	Step ..	2·26	1914-15, 1930-31, 1934-35	− 0·008	+ 0·005	+0·013
23	,,	(Type C) at Colaba	2·93	,,	+ 13·816	+ 13·846	+0·030
41	,,	(Type B) at Colaba	2·94	1930-31, 1934-35	+ 12·205	+ 12·234	+0·029
42	,,	Flooring G.T. Mark (Observatory) ..	2·98	,,	+ 14·149	+ 14·177	+0·028
2	,,	S.B.M., Bombay ..	0·00	1877-78, 1906-07, 1910-11	0·000	0·000	0·000
1	,,	Step ..	0·38	,,	+ 0·013	+ 0·037	+0·024
81*	,,	Step ..	0·39	1914-15	+ 0·113	+ 0·139	+0·026
82*	,,	Step ..	0·73	,,	− 0·703	− 0·676	+0·027
10	,,	Step ..	0·79	1877-78, 1906-07, 1910-11	− 0·651	− 0·621	+0·030
35	,,	Step ..	0·94	1914-15	+ 2·584	+ 2·591	+0·007
129*	,,	Stone ..	1·15	,,	− 2·977	− 2·951	+0·026
2	,,	S.B.M., Bombay ..	0·00	1877-78, 1906-07, 1910-11	0·000	0·000	0·000
34	,,	Plinth ..	0·23	1930-31, 1934-35	− 4·711	− 4·694	+0·017
29	,,	Step ..	1·40	,,	− 4·488	− 4·479	+0·009
30	,,	E.B.M., Bombay ..	1·44	,,	− 5·497	− 5·490	+0·007
2	,,	S.B.M., Bombay ..	0·00	1877-78, 1906-07, 1910-11	0·000	0·000	0·000
105*	,,	Stone seat ..	0·69	1914-15	+ 2·805	+ 2·834	+0·029
79*	,,	Step ..	1·25	,,	− 3·818	− 3·804	+0·014
76*	,,	Plinth ..	2·40	,,	− 4·788	− 4·859	−0·071
74*	,,	Stone pillar ..	2·94	,,	− 4·567	− 4·536	+0·031
73*	,,	Sill ..	3·21	,,	+ 0·384	+ 0·409	+0·025
71*	,,	Step ..	3·84	,,	− 3·914	− 3·883	+0·031

(*Continued*)

* B.M's. from "Supplement to the levelling pamphlet 47, Island of Bombay corrected to 1937".

TABLE 2.—*Check-levelling.*—(contd.)

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1947–48 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling (published values)	Check-levelling 1947–48	
			miles		*feet*	*feet*	*feet*
			At Burdwān on lines Nos. 70 A & 74				
116	73 M	(Type A) at Burdwān	0·00	1913-14, 1916-17	0·000	0·000	0·000
115	,,	S.B.M., Burdwān ..	0·04	,,	+ 5·117	+ 5·095	−0·022
114	,,	Pillar ..	0·19	1914-15, 1916-17	+ 5·335	+ 5·323	−0·012
136	,,	Stone coping ..	0·95	1925	+ 10·505	+ 10·496	−0·009
138	,,	Stone coping ..	1·04	,,	+ 11·610	+ 11·596	−0·014
			At Calcutta on lines Nos. 74, 77 & 121				
353	79 B	(Type B) at Calcutta ..	0·00	1882-83, 1894-95, 1899-1902	0·000	0·000	0·000
453	,,	Step ..	1·99	1924-25, 1927-28	+ 2·685	+ 2·654	−0·031
906	,,	Step ..	2·26	,,	+ 2·527	+ 2·494	−0·033
455	,,	Stone flooring ..	2·24	,,	+ 3·506	+ 3·510	+0·004
917	,,	Stone ..	2·06	,,	+ 5·318	+ 5·305	−0·013
918	,,	S.B.M., Howrah ..	2·24	,,	+ 2·139	+ 2·158	+0·019
31	,,	Pavement ..	1·43	1862-63, 1882-83	+ 1·092	+ 1·091	−0·001
364	,,	Step ..	2·69	1882-83, 1894-95, 1899-1902	+ 2·694	+ 2·672	−0·022
368	,,	S.B.M., Calcutta ..	3·43	,,	+ 2·074	+ 2·104	+0·030
355	,,	Step ..	2·79	,,	+ 4·288	+ 4·242	−0·046
894 (*356*)	,,	Step ..	3·20	,,	+ 4·296	+ 4·291	−0·005
357	,,	Pavement ..	3·80	,,	+ 12·880	+ 12·852	−0·028
988	,,	Pedestal ..	1·98	1936-37	+ 3·687	+ 3·671	−0·016
989	,,	Pedestal ..	1·65	,,	+ 6·051	+ 6·043	−0·008
990 (*896, 32*)	,,	Fountain ..	0·73	1882-1902, 1926-27, 1927-28	+ 0·771	+ 0·752	−0·019
991	,,	Plinth ..	0·70	1927-28	+ 3·589	+ 3·568	−0·021
994	,,	S.B.M., Howrah bridge ..	0·29	1936-37	− 0·262	− 0·262	0·000
992	,,	Step ..	0·29	,,	+ 1·970	+ 1·956	−0·014
897	,,	Pavement ..	0·23	1927-28, 1936-37	+ 3·105	+ 3·096	−0·009
993 (*878*)	,,	Seat ..	0·31	,,	+ 1·490	+ 1·480	−0·010
874 (*358*)	,,	Coping ..	4·40	1882-1902, 1926-27	− 0·757	− 0·818	−0·061
875 (*359*)	,,	Coping ..	4·43	,,	− 0·761	− 0·814	−0·053

(Continued)

TABLE 2.—*Check-levelling.*—(contd.)

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1947-48 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling (published values)	Check-levelling 1947-48	
			miles		*feet*	*feet*	*feet*
			At Diamond Harbour on lines Nos. 74 A & 74 B				
91	79 B	Step ..	0·00	1882-83	0·000	0·000	0·000
92	,,	Type 'B' ..	0·01	1881-83	+ 7·903	+ 7·683	−0·220
174	,,	Marble slab ..	1·40	1881-83	+ 10·857	+ 10·831	−0·026
			At Hardwār on lines Nos. 61 B & 61 C				
16	53 K	Coping ..	0·00	1908-09	0·000	0·000	0·000
18	,,	Coping ..	0·24	,,	+ 0·065	− 0·060	−0·125
10	,,	Bridge ..	0·65	1908	− 27·687	− 27·464	+0·223
11	,,	Stone slab ..	0·70	,,	− 22·442	− 22·256	+0·186
9	,,	Plinth ..	1·65	,,	− 28·091	− 27·854	+0·237
8	,,	Plinth ..	2·65	,,	− 21·080	− 20·842	+0·238
7	,,	Plinth ..	3·65	,,	− 20·860	− 20·657	+0·203

TABLE 2.—*Check-levelling*.—(contd.)

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1948–49 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling (published values)	Check-levelling 1948–49	
			miles		*feet*	*feet*	*feet*
				At Kolhāpur on line No. 29			
23	47 L	E.B.M., Kolhāpur ..	0·00	1877-79	0·000	0·000	0·000
22	„	Step ..	0·85	„	− 1·617	− 2·216	−0·599
				At Hathkhamba on line No. 122			
342	47 L	Rock ..	0·00	1946-47	0·000	0·000	0·000
343	„	Rock ..	0·35	„	+ 35·557	+ 35·556	−0·001
344	„	Rock ..	0·96	„	+ 15·148	+ 15·151	+0·003
341	„	Rock ..	0·56	„	− 21·701	− 21·695	+0·006
340	„	Wheel-guard stone ..	1·85	„	− 50·169	− 50·152	+0·017
				At Belgaum on line No. 29			
37	48 I	S.B.M., Belgaum ..	0·00	1877-79	0·000	0·000	0·000
32	„	Flooring ..	0·74	„	− 73·329	− 73·336	−0·007
33	„	Step ..	1·05	„	− 68·212	− 68·217	−0·005
40	„	E.B.M., Belgaum ..	2·48	„	− 49·871	− 49·847	+0·024
			2·28*			− 49·846*	+0·025
				At Hubli on lines Nos. 16 & 17			
1	48 M	E.B.M., Hubli ..	0·00	1907-08	0·000	0·000	0·000
2	„	Paving stone ..	0·19	„	+ 15·543	+ 15·505	−0·038
3	„	Flooring ..	0·26	„	+ 18·166	+ 18·160	−0·006
52	„	Capstone ..	0·73	„	− 71·077	− 71·148	−0·071
50	„	Capstone ..	3·54	„	− 94·117	− 94·201	−0·084
				At Kārwār on line No. 17			
1	48 J	E.B.M., Kārwār ..	0·00	1907-08	0·000	0·000	0·000
2	„	Rock ..	0·14	„	− 1·155	− 1·163	−0·008
4	„	Rock ..	1·26	„	− 0·782	− 0·798	−0·016
6	„	Rock ..	2·24	„	+ 21·519	+ 21·582	+0·063
7	„	Rock ..	3·25	„	+137·528	+137·544	+0·016
48	„	Capstone ..	0·11	„	− 4·766	− 4·932	−0·166
49	„	Rock ..	0·15	„	− 3·067	− 3·070	−0·003

(*Continued*)

* **Value obtained through another route.**

TABLE 2.—*Check-levelling*—(contd.)

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling: No.	Degree sheet	Description	Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by: Date of original levelling	Orginal levelling (published values)	Check-levelling 1948–49	Difference (check – original). The sign + denotes that the height was greater and the sign −, less in 1948–49 than when originally levelled
			miles		*feet*	*feet*	*feet*
		At Raipur on lines Nos. 116, 117 & 118					
173 (*75*)	64 G	S.B.M., Raipur ..	0·00	1935-36, 1937-38	0·000	0·000	0·000
48	,,	Sill ..	0·46	,,	− 16·224	− 16·221	+0·003
237	,,	Culvert ..	0·53	1937-41	− 19·393	− 19·428	−0·035
171	,,	Culvert ..	1·45	1935-36, 1937-38	− 11·242	− 11·213	+0·029
174 (*76*)	,,	Step ..	1·63	,,	− 14·801	− 14·758	+0·043
170	,,	Step ..	1·85	,,	− 23·539	− 23·541	−0·002
176 (*77*)	,,	Step ..	2·00	,,	− 23·522	− 23·515	+0·007
175 (*46*)	,,	Step ..	2·10	,,	− 25·252	− 25·247	+0·005
177 (*45*)	,,	Pavement ..	2·54	,,	− 30·428	− 30·410	+0·018
178 (*79*)	,,	Culvert ..	3·26	,,	− 53·154	− 53·131	+0·023
179 (*43*)	,,	Platform ..	3·50	,,	− 38·804	− 38·777	+0·027
180	,,	Bridge ..	3·71	1935-38	− 40·554	− 40·521	+0·033
172	,,	Coping ..	0·51	1935-36, 1937-38	+ 0·427	+ 0·485	+0·058
		At Vizianagram on lines Nos. 36, 39 & 125					
237	65 N	S.B.M., Vizianagram	0·00	1938-39-40	0·000	0·000	0·000
233	,,	Flooring ..	0·04	,,	+ 2·036	+ 2·031	−0·005
232	,,	Step ..	0·16	,,	− 3·373	− 3·367	+0·006
231	,,	Step ..	0·34	,,	− 5·860	− 5·853	+0·007
238	,,	Culvert ..	0·75	,,	+ 11·293	+ 11·264	−0·029
		At Vizianagram on lines Nos. 36, 39 & 125					
236	65 N	Prism ..	0·00	1938-39-40	− 0·912	− 0·914	−0·002
235	,,	Prism ..	0·00	,,	− 0·884	− 0·884	0·000
234	,,	Iron bolt ..	0·00	,,	− 0·379	− 0·381	−0·002
228	,,	Bridge ..	0·35	,,	− 1·304	− 1·273	+0·031
230	,,	Culvert ..	0·64	,,	− 20·834	− 20·832	+0·002
239	,,	Bridge ..	1·11	,,	− 22·309	− 22·316	−0·007
175	,,	Bridge ..	1·20	,,	− 20·908	− 20·912	−0·004
227	,,	Stone ..	1·64	,,	− 19·408	− 19·373	+0·035
226	,,	Step ..	0·50	,,	− 21·432	− 21·425	+0·007
225	,,	Furlong-stone .	0·59	,,	− 29·108	− 29·122	−0·014
35	,,	Kerb ..	0·76	,,	− 30·198	− 30·246	−0·048
18	,,	Culvert ..	0·70	,,	− 22·838	− 22·842	−0·004
17	,,	Culvert ..	1·70	,,	− 31·930	− 31·909	+0·021
16	,,	Bridge ..	1·96	,,	− 36·254	− 36·209	+0·045
15	,,	Bridge ..	2·74	,,	− 47·984	− 47·926	+0·058

(Continued)

TABLE 2.—*Check-levelling.*—(contd.)

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1948-49 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling (published values)	Check-levelling 1948-49	
			miles		*feet*	*feet*	*feet*
			At Vizagapatam on line No. 36				
71	65 O	S.B.M., Vizagapatam	0·00	1894-95	0·000	0·000	0·000
75	,,	(Type C) Vizagapatam ..	0·35	,,	+ 1·154	+ 1·158	+0·004
74	,,	Flooring ..	0·40	,,	+ 0·249	+ 0·231	−0·018
73	,,	Plinth ..	0·75	,,	+ 7·912	+ 7·880	−0·032
72	,,	Step ..	0·99	,,	− 2·323	− 2·395	−0·072
			At Calcutta on lines Nos. 77 & 121				
353	79 B	(Type B) at Calcutta ..	0·00	1882-83, 1894-95, 1899-1902	0·000	0·000	0·000
827	,,	Step ..	1·31	1924-25, 1927-28	+ 1·954	+ 1·947	−0·007
920	,,	Plinth ..	1·44	,,	− 1·110	− 1·136	−0·026
919	,,	Step ..	1·94	,,	+ 4·655	+ 4·650	−0·005
918	,,	S.B.M., Howrah ..	2·28	,,	+ 2·139	+ 2·160	+0·021
453	,,	Step ..	2·39	,,	+ 2·685	+ 2·669	−0·016
917	,,	Stone ..	2·44	,,	+ 5·318	+ 5·316	−0·002
455	,,	Flooring ..	2·63	,,	+ 3·506	+ 3·518	+0·012
906	,,	Brick ..	2·68	,,	+ 2·527	+ 2·501	−0·026
909	,,	S.B.M., Sibpur ..	3·40	,,	+ 5·655	+ 5·673	+0·018
			At Diamond Harbour on lines Nos. 74 A & 74 B				
91	79 B	Step ..	0·00	1882-83, 1947-48	0·000	0·000	0·000
92	,,	(Type B) at Diamond Harbour ..	0·01	1881-83,	+ 7·903	+ 7·684	−0·219
	,,	,,	,,	1947-48	+ 7·683	+ 7·684	+0·001
174	,,	Marble slab ..	1·43	,,	+ 10·857	+ 10·842	−0·015
	,,	,,	,,	,,	+ 10·831	+ 10·842	+0·011
1/B	,,	Milestone ..	0·50	1947-48	+ 11·232	+ 11·241	+0·009
1/C	,,	Platform ..	0·70	,,	+ 9·189	+ 9·208	+0·019
3	,,	Bridge ..	0·18	,,	+ 13·095	+ 13·097	+0·002
4/2	,,	Type 'B' ..	0·78	,,	− 3·522	− 3·521	+0·001
4	,,	Milestone ..	1·03	,,	+ 10·628	+ 10·628	0·000
4/1	,,	Rail ..	1·34	,,	+ 1·896	+ 1·897	+0·001

(*Continued*)

TABLE 2.—*Check-levelling.*—(concld.)

Discrepancies between the old and new heights of bench-marks.

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1948–49 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling (published values)	Check-levelling 1948–49	
			miles		*feet*	*feet*	*feet*
		At Jaleswar on line No. 121					
90 (29)	73 O	E.B.M., Jaleswar ..	0·00	1927-28	0·000	0·000	0·000
93	,,	Culvert ..	1·14	,,	+ 5·629	+ 5·510	−0·119
100	,,	S.B.M., Muhamadnagar ..	4·11	,,	+ 2·994	+ 2·811	−0·183
		At Hoshangābād on line No. 115					
87	55 F	S.B.M., Hoshangābād ..	0·00	1935-36 37	0·000	0·000	0·000
86	,,	Prism of S.B.M. ..	0·00	,,	− 0·668	− 0·667	+0·001
85	,,	Prism of S.B.M. ..	0·00	,,	− 0·675	− 0·677	−0·002
83	,,	Step ..	0·13	,,	+ 4·312	+ 4·328	+0·016
88	,,	Flooring ..	0·05	,,	+ 0·890	+ 0·918	+0·028
89	,,	Plinth ..	0·11	,,	− 0·532	− 0·508	+0·024
93	,,	Coping ..	0·71	,,	+ 7·471	+ 7·487	+0·016
92	,,	Flooring ..	0·75	,,	+ 8·474	+ 8·437	−0·037
		At Itārsi on line No. 115					
67	55 F	Pier ..	0·00	1935-36-37	0·000	0·000	0·000
66	,,	Flooring ..	1·66	,,	+ 9·808	+ 9·771	−0·037
65	,,	Flooring ..	1·79	,,	+ 9·887	+ 9·724	−0·163
63	,,	Coping ..	2·00	,,	+ 15·457	+ 15·448	−0·009
62	,,	Flooring ..	2·49	,,	+ 11·588	+ 11·645	+0·057
61	,,	Culvert ..	2·67	,,	+ 11·966	+ 11·956	−0·010
		At Mhow on line No. 111					
83	46 N	S.B.M., Mhow ..	0·00	1929-31	0·000	0·000	0·000
129	,,	Stone ..	0·15	,,	+ 4·162	+ 4·162	0·000
128	,,	Culvert ..	0·71	,,	− 22·175	− 22·250	−0·075
86	,,	Flooring ..	1·05	,,	+ 3·737	+ 3·754	+0·017
54	,,	E.B.M., Mhow ..	1·10	,,	− 43·065	− 43·047	+0·018

TABLE 3.—*Comparison between old (1908) and new (1947) levelling of branch-line 61 B. (Nojli to Hardwār), Portion Roorkee–Hardwār.*

B.M. No.	Distance from S.B.M., Roorkee		Description	Observed Height in terms of S.B.M., Roorkee		Difference (New–Old)	Probable error of difference in column 6
				New 1947	Old 1908		
1	2		3	4	5	6	7
	Miles	Chains					
63/53 G	0	00	S.B.M., Roorkee ..	0·000	0·000	0·000	± 0·000
65/53 G	1	68	Plinth of milestone No. 19 ..	− 3·977	− 4·138	+ 0·161	0·003
1/53 K	10	77	Plinth of milestone No. 10 ..	+29·315	+29·291	+ 0·024	0·026
2/53 K	11	79	Plinth of milestone No. 9 ..	+21·864	+21·806	+ 0·058	0·027
3/53 K	12	79	Plinth of milestone No. 8 ..	+19·620	+19·552	+ 0·068	0·029
5/53 K	16	19	Plinth of milestone No. 5 ..	+63·295	+63·235	+ 0·060	0·034
6/53 K	17	19	Plinth of milestone No. 4 ..	+59·387	+59·310	+ 0·077	0·035
7/53 K	18	19	Plinth of milestone No. 3 ..	+68·026	+67·908	+ 0·118	0·037
8/53 K	19	19	Plinth of milestone No. 2 ..	+67·841	+67·686	+ 0·155	0·038
9/53 K	20	19	Plinth of milestone No. 1 ..	+60·829	+60·675	+ 0·154	0·040
10/53 K	21	19	On Māyāpur regulator bridge ..	+61·219	+61·078	+ 0·141	0·042
11/53 K	21	23	Stone slab in canal bungalow ..	+66·427	+66·324	+ 0·103	0·042

Chapter III

GRAVITY

BY B. L. GULATEE, M.A. (CANTAB.)

24. **Summary.**—An indication of the future programme of gravity observations in India was given in the last year's report (see Technical Report 1947, Part III, Para 34). It was pointed out that it was intended to commence work on a new 10-mile network of gravimeter stations covering the whole of India. In pursuance of this programme, 101 new gravimeter stations (24 in West Bengal and 77 in Madhya Pradesh) were established with the Frost gravimeter during the period under report. The area covered is shown by blue colourwash in Chart X and amounts roughly to 8,500 square miles.

Gravimetric observations have been taken at twelve standard and twenty other primary protected bench-marks of the Primary Level net of India.

In addition to the above, thirty-six old pendulum stations were also revisited.

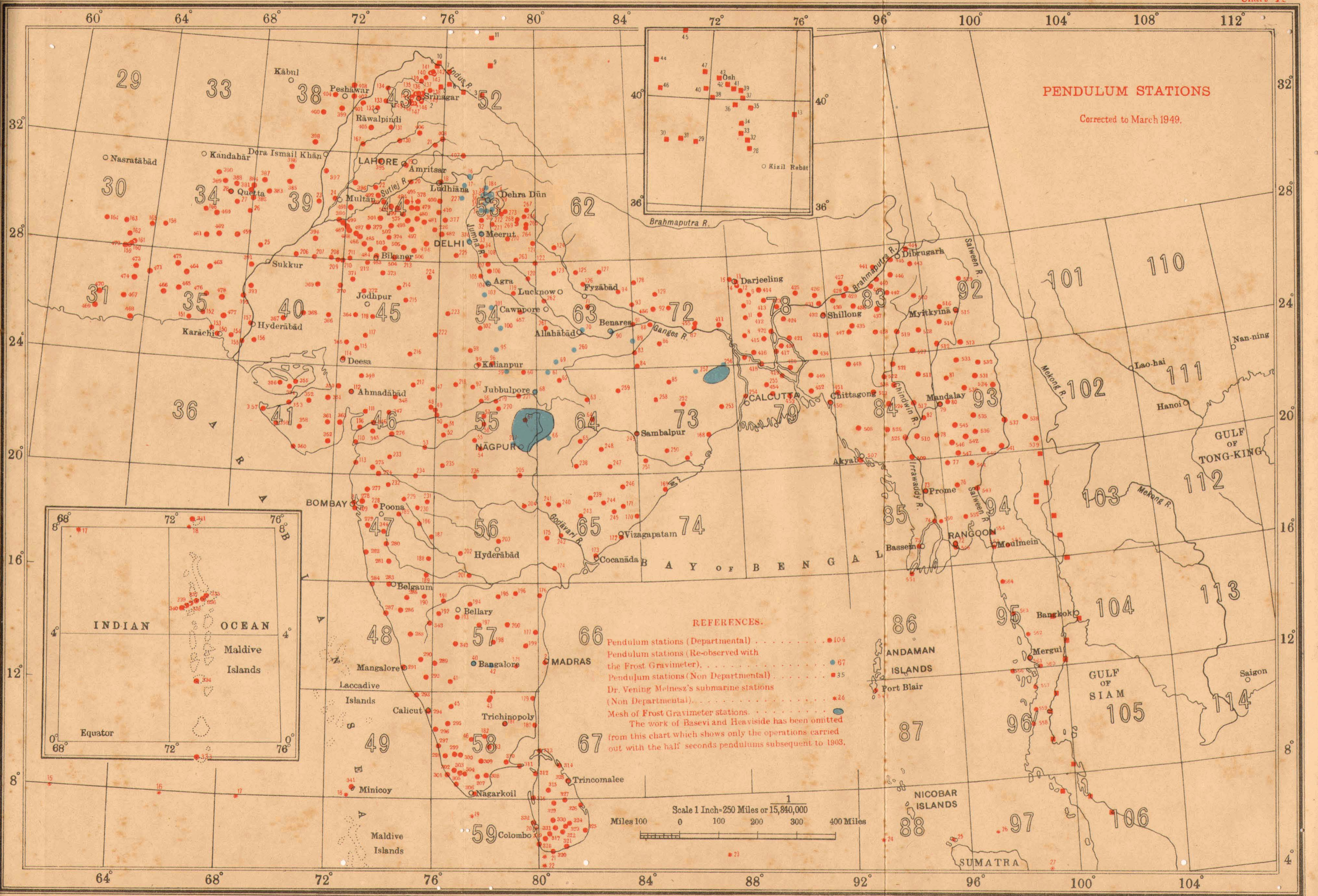
An important connection of the base station at Dehra Dūn was also effected with the group of five gravity stations at Delhi recently observed by Dr. G. P. Woollard of the Woods Hole Oceanographic Institution (U.S.A.) as part of his world net of gravity stations. This has gone a long way towards finalizing the absolute value of gravity at Dehra Dūn about which there were always some doubts.

The following paragraphs give a detailed account of the field work mentioned above.

25. **Narrative.**—(*a*) *Field Season 1947–48.* A detachment consisting of two sections, a position and height fixing Section and a Gravimeter Section, was organized. The position and height fixing Section was under the direct charge of Mr. A. K. Bhattacharjee (Class II) assisted by four Surveyors and 26 *khalāsīs*. The Gravimeter Section comprised of Mr. S. Vaikuntanathan (Class II), 1 Surveyor, 1 Computer and 6 *khalāsīs*.

The position and height fixing Section left Dehra Dūn by rail on 20th October 1947 and arrived at Rānīganj on 27th October 1947. The Gravimeter Section left Dehra Dūn on 5th November 1947 by road in a 15-cwt. Dodge Weapon Carrier in which the Gravimeter was fitted by making suitable alterations in the body of the vehicle. This section arrived in Rānīganj on 13th November 1947. Both

Chart X



Reg.No.91M/G.B '48 (C.O)S.I- 400-375 '49.

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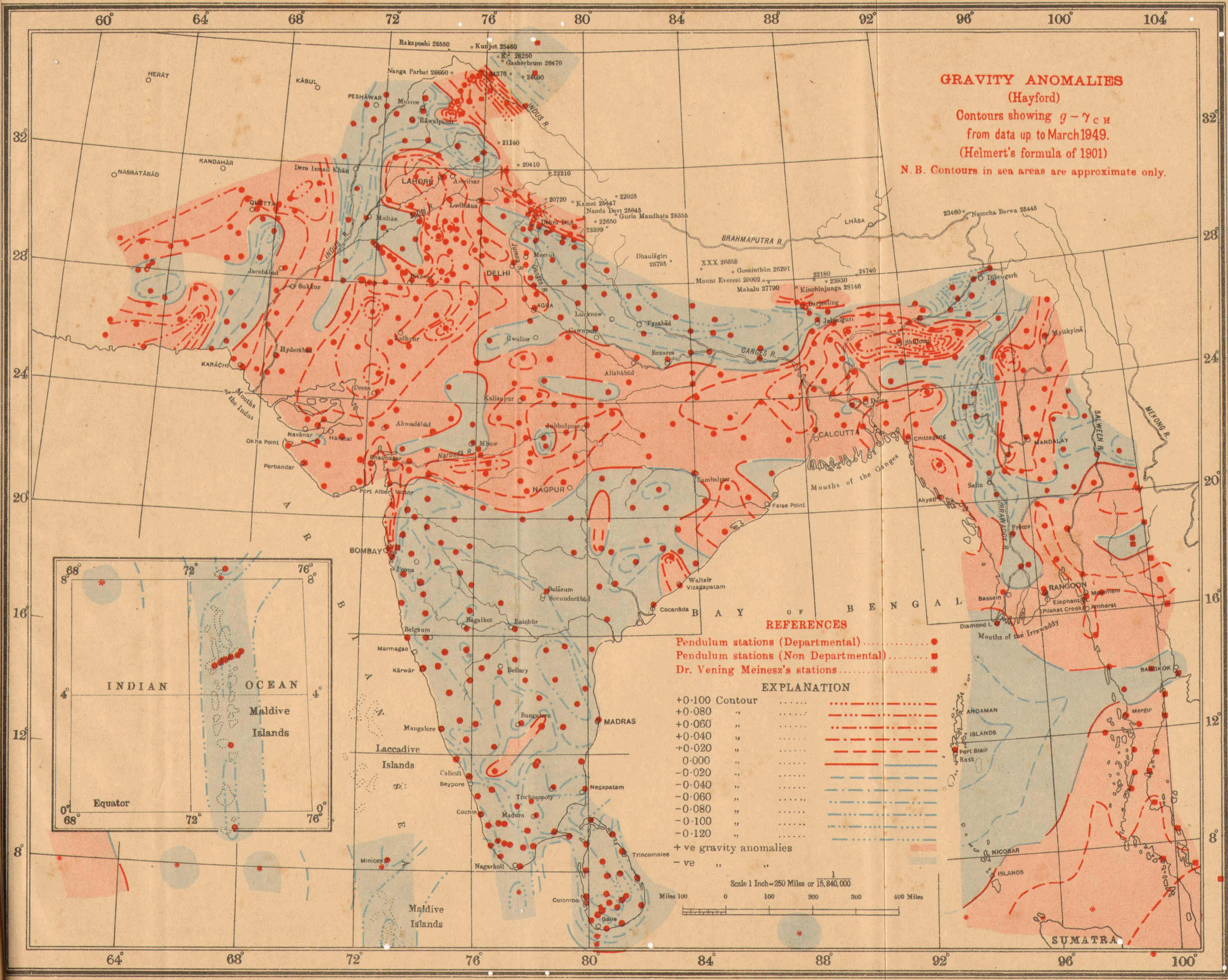
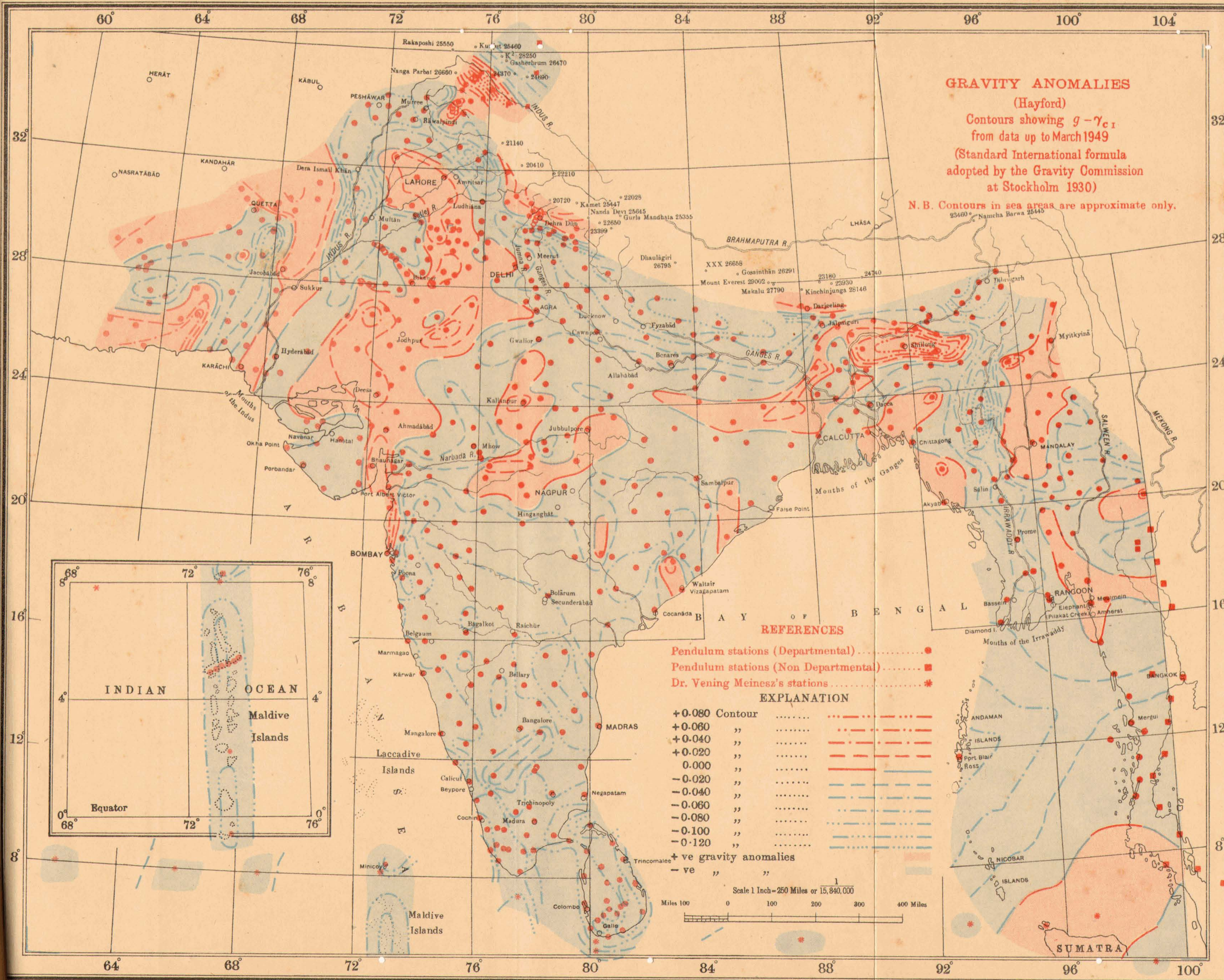


HELIO. S.I.O. (P.Z.O.)



REG. No 95 M/G.B. 1939 (C.O.)-S. 1:-390-40' 350-44' 315.1700-48' 375-49.

HELIO. S.I.O. (P. Z .O.).

sections continued work in the Rānīganj Coal-fields area of West Bengal till 18th December 1947. For transport two 15-cwt. Dodge Weapon Carriers were obtained on loan from the Director, Eastern Circle, Survey of India, Calcutta. Some difficulty was experienced in securing timely supplies of petrol for these vehicles. On the whole the use of motor transport helped to speed up work and consequently proved economical. The health of the detachment remained good and there were no casualties.

On the completion of work in the Rānīganj Coal-fields area the section under Mr. Bhattacharjee left Burdwan by rail via Calcutta for Kamptee (Madhya Pradesh) on 22nd December 1947 and arrived at Kamptee on 29th December 1947. This Section returned to Dehra Dūn on 1st April 1948 after completing the programme for the year.

The Gravimeter Section left Rānīganj on 19th December 1947 in the Weapon Carrier in which the Gravimeter was fitted, and arrived at Lakhnadon on 25th December 1947. This section completed its programme on 6th March 1948 and returned to Dehra Dūn on 14th March 1948.

(*b*) *Field Season 1948–49.* During the previous field season positions and heights of some of the stations at which observations with the gravimeter were made could not be fixed. A detachment under Mr. A. K. Bhattacharjee, with three Surveyors, one Computer and 28 *khalāsīs* left Dehra Dūn on 15th October 1948, arrived at Gondia on 19th October 1948 and commenced work on 21st October 1948. Throughout the field season the detachment was employed on position and height fixing of the gravimetric stations. The work was closed at Bālāghāt on 15th January 1949. Thereafter Mr. A. K. Bhattacharjee and Mr. J. K. Donald were ordered to proceed to Hoshangābād and Mhow respectively to carry out secondary levelling for the Executive Engineer, Lower Narbada Division (see Chapter II, Para 21) and the rest of the detachment returned to Dehra Dūn.

The climate of the area was not healthy and most of the personnel suffered from malaria and jaundice.

26. **Position Fixing.**—Both in the Rānīganj and Nāgpur areas the gravimetric stations were sited close to the roads with a view to easy access. All available triangulation and traverse data in the area was plotted on a chart and the sites of the gravimetric stations were selected in such a way that the co-ordinates of each station could be derived most economically either by a short line of traverse between two known points or by observing a couple of triangles based on existing triangulation data. In some cases the position was fixed by resection from nearby stations and intersected points with a Sun or Polaris azimuth observed. A small Wild and a Tavistock theodolite were used for observation. The co-ordinates were generally fixed correct to about 10 to 20 feet and in a very few cases where data was sparse to about 50 feet.

27. **Heights.**—The determination of heights of gravimetric stations to the nearest foot was a serious problem as levelling bench-

marks in India are few and far between. Each station was connected to levelling bench-marks by tertiary levelling and tacheometric levelling, the latter being much quicker.

In addition, to get an idea of the performance of Paulin barometers, a battery of 4 barometers was taken to the field, two of which were used for field observations and the other two for base observations. The routine of observations, computations and the conclusions as to the accuracy achieved are described in Chapter VII.

The final heights of stations in Table 3 are the mean of the levelling and tacheometric heights.

28. **Selection and marking of gravity stations.**—Gravimetric stations were chosen in the main about 10 miles apart with due regard to easy fixation of their positions and heights by the survey crew and easy access by transport. The stations consist of a cement concrete pillar, 8 inches square at base dressed to the form of a frustum of a pyramid terminating in a square of 4-inch side, embedded in the ground. The upper surface of the pillar is flush with the ground and is covered by a cairn 3 feet high. The details of the location of each station and the distances and bearings of the surrounding objects have been recorded. These stations have been handed over to the local district authorities for maintenance and protection.

29. **Routine of observations.**—At the beginning of each day's work with the gravimeter, observations were made for 15 to 20 minutes at the base station to ensure that the instrument was in thermal equilibrium and free from erratic drift.

The field observer's routine was to set up, level, read and record the readings of the Frost Gravimeter, and to take two samples of soil at each station for density determinations. He also read two Paulin aneroids for pressure and height and recorded the outside temperature.

In addition he had to write out the description of the station and enter the topography around it for a radius of about 560 feet in all directions with a view to getting an estimate of the terrain correction at the station.

The gravimeter observer was accompanied by the Magnetic Variometer observer who recorded the values of magnetic Vertical Force at each station. The base observer used to read the magnetic V.F. Variometer once every 15 minutes and Paulin aneroids every half hour.

30. **Characteristics of the Gravimeter.**—Drift is an inherent characteristic of the gravimeter and depending on its rate per hour, the instrument has to be brought to the starting station after every three or four hours. In the actual fieldwork, a maximum drift of 5 dial division corresponding to 0·4 mgals only was allowed in 3 to 4 hours; the length of each circuit was limited to about 40 miles. In order to keep down the drift to about 0·1 mgal per hour great care is needed to see that (i) the gravimeter is kept in thermal

equilibrium and the voltage of the accumulators supplying heating current to its elements is not allowed to drop down, (ii) that it is not exposed to direct sunlight even for a short time and (iii) that it is not subjected to severe jolts during transportation. Excessive drifts are produced when there is a large temperature difference between the gravimeter and the outside temperature.

It is imperative for a satisfactory working of the instrument that the 6-volt accumulators should have their full voltage. As the gravimeter section was to work in areas remote from towns where no facilities existed for recharging the accumulators, a special fitting was made to the gravimeter transport for the purpose. The 15-cwt. Weapon Carrier had a battery of 12 volts. To charge the instrument battery of 6 volts simultaneously with the truck battery, an arrangement as shown in Fig. 1 was used. An ammeter was introduced in the circuit to keep a check on the charging current. The arrangement worked fairly satisfactorily throughout the season.

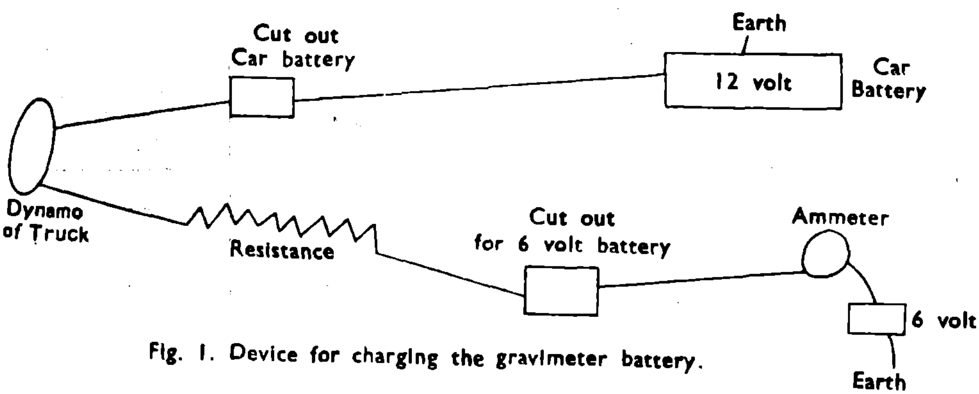


Fig. 1. Device for charging the gravimeter battery.

The Frost Gravimeter has a total range of 120 mgals and when the difference of gravity to be measured exceeds this amount, it has to be reset. After each resetting, a wait of about 2 hours is advisable before resuming work. The total number of resettings made at various places during the period under report is as below :—

			No. of settings
Rāniganj area (W. Bengal)		..	2
Nāgpur area ..	..	..	3
Dehra Dūn–Mussoorie	..	..	3
Dehra Dūn–Simla	..	..	4
Dehra Dūn–Delhi	..	..	2

31. **Calibration of Meter Factor.**—Readings can be taken with the Frost Gravimeter to 0·01 mgals and the mean error of observations with it can be reckoned as $\pm 0 \cdot 05$ mgals. The pendulum observations have a mean error about 40 times greater than this and so cannot be used either as a check on the gravimeter or for the derivation of its calibration constant. In a country well supplied with precise gravimetric bench-marks, the calibration of a new gravimeter is easy. An alternative method is to make measurements at the bottom and top of a tall skeleton tower or an isolated tall building and determine the calibration factor from the change in gravity after applying the usual Free-Air correction.

In India neither of these facilities are available. The only net of gravity work is that established by means of the pendulums which, as has already been mentioned, is of a much lower precision.

The calibration constant of the instrument as supplied by the makers in 1946 was 1 scale division = 0·0809 mgals. This cannot be expected to hold for all time and the following attempts were made to see whether it had changed its value. Firstly observations were made at the top and bottom of Qutab Minar at Delhi with the following results :—

Date	Place	Height	Difference of scale reading	Difference of g by Free-Air formula
		feet	*divisions*	*mgals*
29-1-49	Qutab Minar, Delhi ..	238	268·6	22·37

These give the value of the meter factor to be 1 scale division = 0·0833 mgals.

This determination, however, cannot be considered very reliable on account of two reasons :—

(*a*) The instrument had to be man carried through a narrow winding stair case. This introduces a chance of creep coming in due to jolts. The ideal way is to take it up smoothly in a lift which was not available.

(*b*) The attraction due to the mass of Qutab Minar has not been allowed for. Ignoring of mass correction results in a larger value in the last column and so the meter constant found would be on the high side.

An indirect check on the calibration constant, however, has been afforded by connecting several pendulum stations round

Dehra Dūn with the gravimeter. The table below gives the details :—

TABLE 1.—*Old Pendulum Stations near Dehra Dūn connected with the Gravimeter*

Serial No.	Station	Height	Change in dial divisions between base and field station	Pendulum *minus* gravimeter value		REMARKS
				Meter factor 0·0809	Meter factor 0·0817	
		feet		*mgals*	*mgals*	
1	Dehra Dūn ..	2239	0	..	..	Datum
2	Dunseverick (Mussoorie)..	7128	−3548	− 3·1	− 0·2	
3	Evelyn Villa (Mussoorie)..	6917	−3338	− 1·5	+ 1·2	
4	Rājpur ..	3334	− 754	− 1·6	− 1·0	
5	Chakrāta ..	6933	−3016	− 6·7	− 4·3	
6	Roorkee ..	867	+ 816	+ 0·7	0·0	
7	Nojli ..	879	+ 989	+ 1·8	+ 1·0	
8	Fatehpur ..	1434	+1038	+ 2·1	+ 1·3	
9	Kālsi ..	1684	+ 838	+ 2·0	+ 1·3	
10	Mohan ..	1660	+ 569	+ 0·8	+ 0·3	
11	Hardwār ..	949	+ 729	− 0·9	− 1·5	
12	Ambāla ..	888	+1694	− 0·1	− 1·5	
13	Kālka ..	2202	+1038	+ 1·6	+ 0·8	
14	Meerut ..	734	+1088	+ 0·2	− 0·7	
15	Delhi ..	715	+1026	+ 0·4	− 0·4	
16	Khurja ..	649	+ 235	+ 1·9	+ 1·7	
17	Agra ..	535	+ 086	+ 0·7	+ 0·7	
18	Hāthras ..	587	+ 148	+ 3·8	+ 3·7	
19	Aligarh ..	612	+ 148	+ 0·6	+ 0·5	
20	Dhanbād ..	761	0	..	..	Datum
21	Suri ..	264	?	+ 1·6	+ 0·8	

The first four stations are at a higher elevation than the base station Dehra Dūn and the others are at a lower elevation. Column 5 which is obtained by using factor 0·0809 shows a significant systematic trend—the discrepancies being positive/negative according as the stations have higher/lower values of gravity than the base station. Although it has to be admitted that the accuracy of pendulum results is only 1 to 2 mgals and that the discrepancies in column 5 are in the main of this order, still an error in calibration constant is indicated as the errors in the pendulum results are random and not systematic.

By selecting a calibration factor of 0·0817, an obvious improvement in the picture of the discrepancies becomes apparent as is seen from column 6. This factor has been derived only by rough trial and error. A rigorous derivation by least squares will be undertaken when some more data has been accumulated.

The above shows the desirability of calibrating the Frost Gravimeter directly against some other gravimeter such as the Worden at the earliest opportunity.

32. Difference Base at Dehra Dūn.—A difference base has been established at Dehra Dūn to keep a check on the constancy of the calibration constant of the instrument. The two stations selected for the purpose are Haig Observatory Bench-mark, Dehra Dūn (Height 2231·6 feet), and Bench-mark No. 169/117 at Rājpur (Height 3334·1 feet). Gravity differences were determined between these stations on different occasions and are tabulated below. They are satisfactorily constant and it can be inferred that no abrupt changes have taken place in the calibration constant of the instrument.

TABLE 2.—*Difference Base (Haig Observatory B.M.—Rājpur B.M.)*

(Distance = 6·63 miles)

No.	Date	Time Taken	Value of g		Total drift in dial divisions
			in dial divisions	in milligals	
		h m			
1	14–10–47	2 17	− 745·7	− 60·327	− 6·8
2	22–10–47	2 00	− 746·0	− 60·351	− 3·6
3	28–4–48	0 55	− 745·7	− 60·327	− 3·3
4	5–10–48	1 05	− 748·0	− 60·485	+ 6·9

33. Reduction of Gravimeter Stations.—Gravimeter measures g to a precision of 0·1 mgal or better but these values cannot be made use of directly for any interpretation work. They have to be reduced to sea-level by applying corrections for altitude, terrain, topography, compensation, etc. These reductions can introduce considerable inaccuracy, and quite a lot of the advantage of the use of a high precise instrument can be lost if the reduction employed is not carefully chosen. Quite different considerations are needed for the choice of the reduction, however, according as the stations have been laid down for geodetic or geophysical purposes.

For geodetic purposes, reductions take count of the effect of the topography and its compensation (according to different hypotheses) for the whole earth and even with the best of care cannot be expected to be more accurate than 1 or 2 mgals because of the inevitable uncertainties in distant zones. For interpretation of broad features, this is quite ample.

For detailed geophysical work, the isostatic reductions are not at all important. The area under operation is very limited and all that is needed is that the effect of the terrain up to a certain distance (say 10 to 15 miles) from the area should be accurately estimated. The distant zones can be neglected altogether and so far as geophysical interpretation is concerned are of no interest as they affect all the stations by the same amount.

Our objective was two-fold :

(i) to establish an accurate framework of stations on which further detailed geophysical prospecting work could be based. This would enable such a local work to be brought in absolute terms.

(ii) to delineate the broad features of curiosities in the earth's crust in as far as they can be revealed by a 10-mile mesh of stations.

For purpose (i), an accurate observed value of gravity is all that is required. Later on, when detailed work for locating economic deposits is carried out in this area, one of these stations could be used as the reference station and could be reduced in the same fashion as the others near it. Precise terrain corrections have to be evaluated to conserve the accuracy of the gravimetric observations.

Objective (ii) leans more on the geodetic side than geophysical and can only reflect regional anomaly structures rather than small local deposits. For this purpose, the observed gravity values have been reduced as follows :—

(*a*) They have been corrected for the usual Free-Air, Bouguer, and Hayford Isostatic reduction and by hypotheses of regional compensation. The results are given in Table 3.

(*b*) Modified Bouguer anomalies in which the attraction of topography is taken count of up to the outer limit of Zone O have also been worked out and included in Table 3.

34. **Interpretation of Gravity Anomalies in the Rānīganj Area.**—Table 3 gives gravity anomalies on seven hypotheses for 30 stations and also the mean anomalies with and without regard to sign.

Curiously enough, Bouguer anomalies are the least and most regular of the lot. Mean Free-Air anomalies are greater than Bouguer but are less than Isostatic anomalies. It is thus abundantly clear that this region is not in Isostatic equilibrium.

The other curious feature is, that the bulk of the Bouguer anomalies are positive indicating under compensation or excess masses underneath.

Chart XIII shows the Hayford Isostatic anomaly contours on the Helmert spheroid at intervals of 5 mgals in red. For comparison the older contours are shown in black by dotted lines. These were based on pendulum observations and were drawn at contour intervals 20 mgals apart, because of the larger spacing of stations and low precision of pendulum results. They are in the main correct but it will be seen what a lot of curiosities can be missed when stations are as far apart as 70 miles. The corresponding modified Bouguer anomalies are shown on Chart XIV.

The most conspicuous features of the Bouguer anomaly map are two regions of gravity highs separated by a gravity low. The alluvium in this area is only a skin and the two intrusions appear to be due to some feature that is intimately bound up with sub-surface geological structure.

A denser net of stations for further investigations is indicated in the neighbourhood of Rānīganj where the steepest gradients occur in the direction AB. The magnitude of the gradients is about 10 mgals per mile which is about ten times the normal gradient.

On the extreme east, near Burdwān, the gravity field becomes rapidly negative due to large thickness of the light sediments. There are hardly any outcrops here on account of this reason.

A quantitative interpretation of the gravity field in terms of the geology of the area is of the utmost importance and will form the subject of a separate paper. A short preliminary discussion is given below.

The anomaly charts show the various formations that occur in the area. In addition to these, there are a number of intrusions of basic rocks in Rānīganj Series. They are such a common feature in this area that they have even increased the density of this formation. These basic intrusions have actually caused a lot of harm as in their process of coming out through the Rānīganj Series, they have burnt a lot of coal.

Basic rocks can only intrude through Rānīganj and not through alluvium, because the alluvium is too recent. But Dalma Trap being ultrabasic and archean can only penetrate through gneisses and not the Rānīganj Series.

In the interpretation two possibilities can arise. The two noses of high anomalies may be due to the eastern extension of Rānīganj Series and basic rock dykes in it. If this is so there are tremendous economic possibilities of presence of coal and borings should immediately be undertaken at the gravity highs. If on the other hand these highs are due to Dalma Trap or gneisses then it may not mean Rānīganj Series at all and the anomalies have no economic

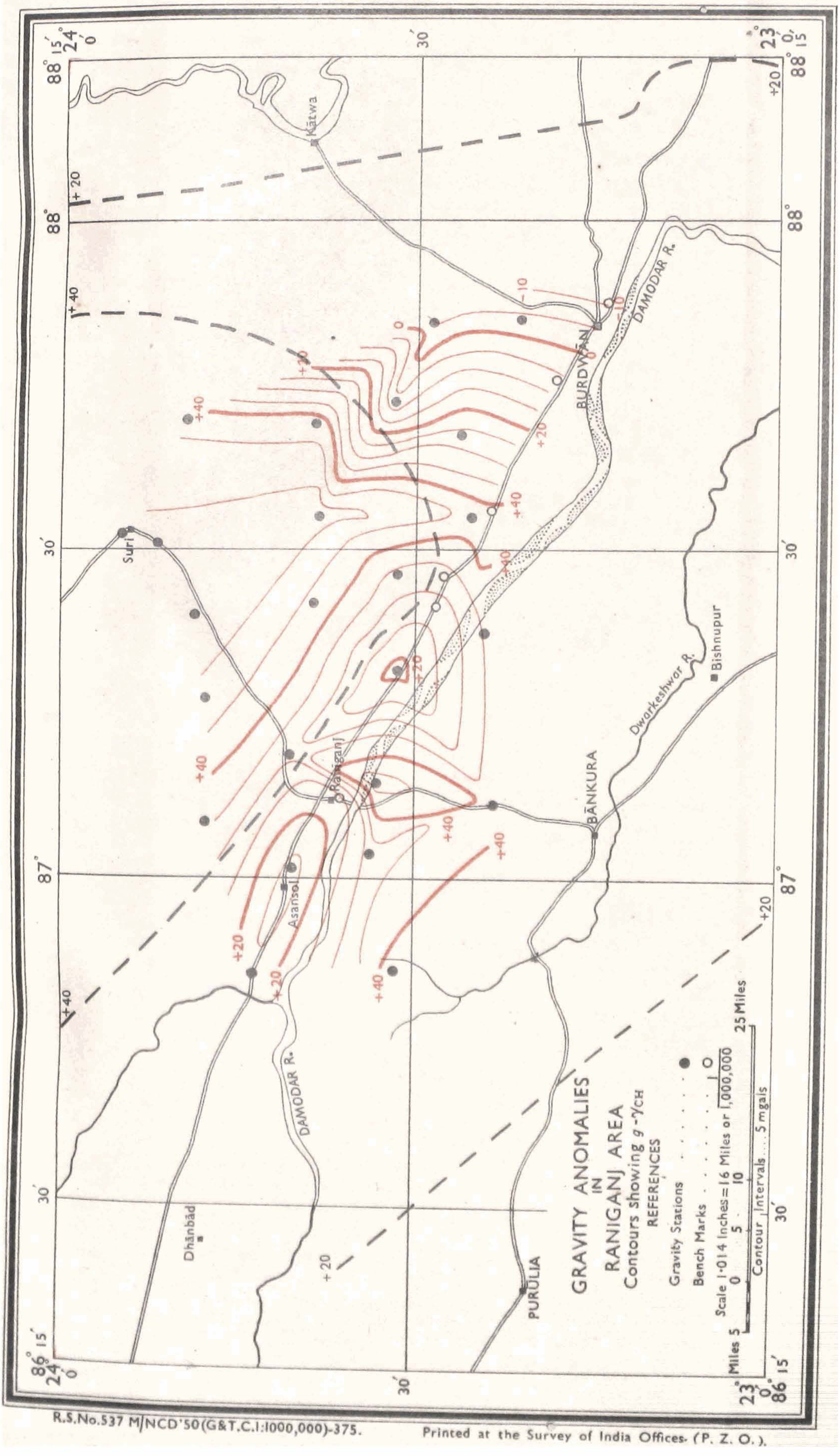


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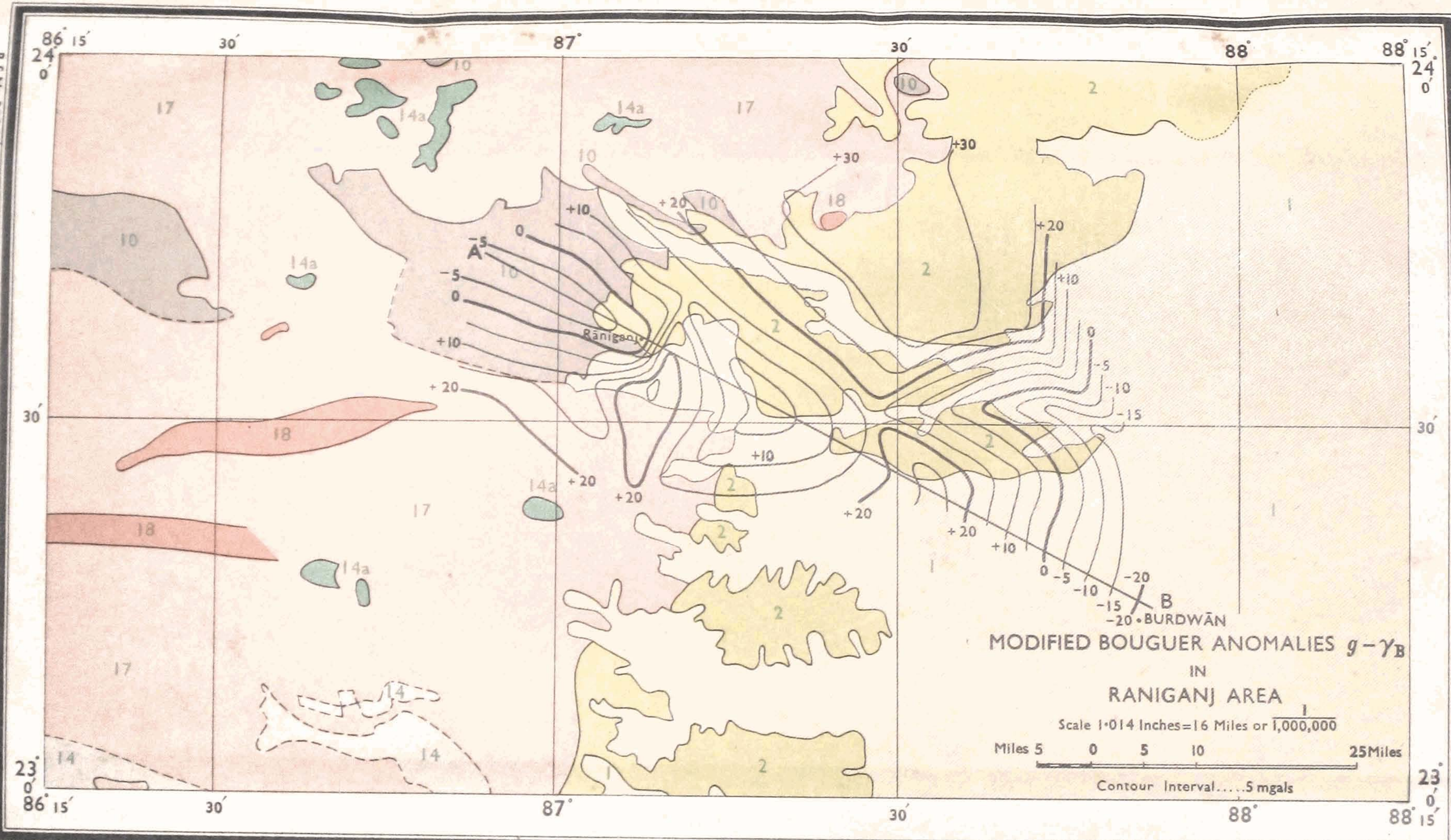
Chart XIV



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Recent Deposits. . . . . 1 · Lower Gondwanas. . . . . 10 · Dalma Trap. . . . . 14a · Granite (and syenite). 18

Older Alluvium, Laterite. . . . . 2 · Dharwar. . . . . 14 · Unclassified crystallines, gneiss. 17

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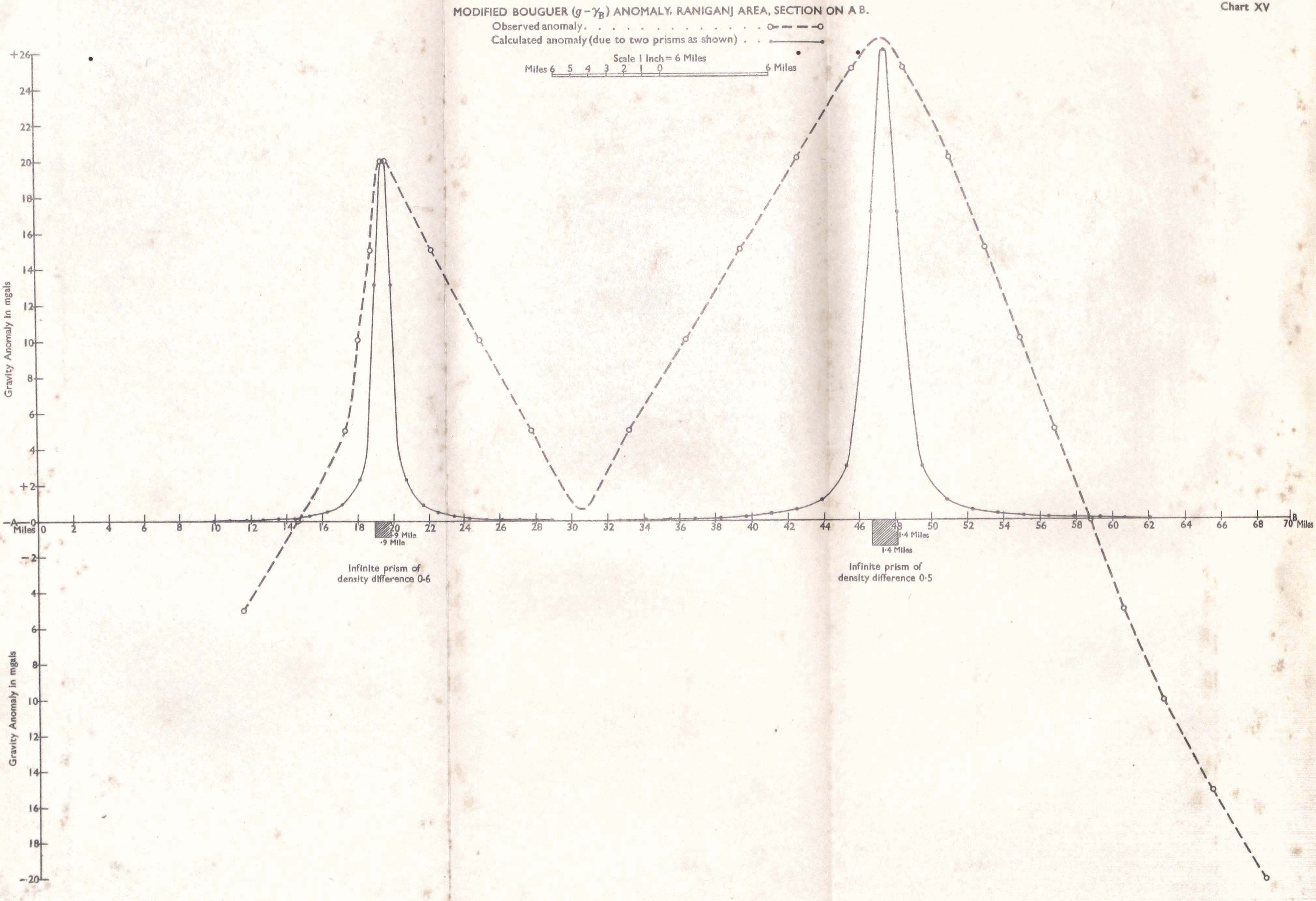

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significance. It would be desirable to put in some more stations in these areas for further detailed study.

The specific gravities of the various formations in this area are:—

Formation	Approximate specific gravity
Alluvium	1·9
Rānīganj Series	2·5
Gneiss	2·65
Dalma Trap	3·0
Basic intrusions in Rānīganj Series	3·0

Densities from surface specimens were found to be of the order of 1·3 to 1·6 in the Rānīganj area. These cannot be regarded as representative as the top sediments are rather loose. To get an estimate of effective density for the area, two "density profiles" were run over a slightly undulating site comprising of about sixteen stations at intervals of 330 feet. The height differences were plotted against a series of elevation correction factors drawn at intervals of 0·002 and it was found that the profile corresponding to density 2·0 was smoother than the others and was more independent of the topography. This is a reasonable value for the surface density.

It would be seen from the above, that density differences of as much as 0·6 are possible amongst the various formations. One over-simplified solution of the mass anomalies that can produce roughly the observed Bouguer section on the line AB is shown in Chart XV, which is drawn on the assumption of two prisms of infinite extent at shallow depth perpendicular to the plane of the paper one having an excess of density of 0·6 and the other an excess of density of 0·5 from the surroundings.

A more detailed discussion taking into account the probable thicknesses of the various formations will be given in a separate research publication as mentioned already.

TABLE 3.—*Gravity Anomalies in*

No.	Sheet No.	Station	Height	Latitude	Longitude	g (Observed value)	HAY $g-\gamma_A$	HAY $g-\gamma_B$	HAY Modified $g-\gamma_B$*
			feet	° ′ ″	° ′ ″	*gals*	*mgals*	*mgals*	*mgals*
1	73 I	G 1 ..	440	23 43 31·7	86 50 59·0	978·8291	+ 4·7	−10·2	− 9·8
2	73 I	G 2 ..	659	31 37·1	86 51 16·2	·8341	+43·5	+21·0	+23·0
3	73 M	G 1 ..	388	47 29·9	87 05 10·7	·8605	+26·8	+13·7	+14·3
4	73 M	G 2 ..	341	33 46·5	02 15·0	·8462	+23·2	+11·6	+11·7
5	73 M	G 3 ..	395	40 39·0	11 04·0	·8490	+23·6	+10·1	+10·8
6	73 M	G 4 ..	314	31 36·1	18 46·2	·8337	+10·6	− 0·1	+ 0·5
7	73 M	G 5 ..	307	40 18·7	00 51·3	·8343	+ 1·0	− 9·4	− 9·0
8	73 M	G 6 ..	245	33 09·4	08 36·1	·8660	+34·7	+26·5	+26·0
9	73 M	G 7 ..	192	25 21·6	32 52·9	·8626	+34·8	+28·4	+28·2
10	73 M	G 8 ..	162	26 11·5	40 32·5	·8485	+17·0	+11·6	+11·4
11	73 M	G 9 ..	184	38 36·0	25 02·0	·8755	+32·5	+26·2	+26·3
12	73 M	G 10 ..	345	23 32·1	06 43·1	·8419	+30·5	+18·9	+18·8
13	73 M	G 11 ..	191	24 05·2	22 06·5	·8493	+22·8	+16·4	+15·9
14	73 M	G 12 ..	207	38 07·7	32 50·9	·8817	+41·3	+34·3	+34·0
15	73 M	G 13 ..	105	21 16·3	50 52·2	·8170	−14·4	−17·9	−18·1
16	73 M	G 14 ..	257	48 32·0	23 55·5	·8897	+42·6	+33·9	+33·9
17	73 M	G 15 ..	319	47 31·1	16 19·4	·8777	+37·5	+26·7	+27·3
18	73 M	G 16 ..	127	38 33·5	41 19·8	·8784	+30·1	+25·8	+25·8
19	73 M	G 17 ..	122	28 46·3	50 31·1	·8224	−15·6	−19·8	−19·8
20	73 M	G 18 ..	108	31 51·9	43 31·5	·8362	− 6·5	−10·2	−10·2
21	73 M	G 19 ..	139	49 25·0	41 40·6	·8900	+30·8	+26·0	+26·1
22	73 M	G 20 ..	260	54 50·0	31 26·4	·8947	+40·8	+32·1	+32·0
23	73 M	G 21 ..	159	51 52·8	30 33·7	·8978	+37·8	+32·4	+32·2
24	73 M	G 22 ..	173	31 46·9	27 34·7	·8599	+23·3	+17·5	+17·3
25	73 M	Rāniganj S.B.M.	322	36 15·6	07 05·8	·8411	+13·6	+ 2·7	+ 2·9
26	73 M	Rājband B.M. ..	218	28 22·0	24 37·1	·8471	+18·5	+11·2	+11·0
27	73 M	Pānagar B.M. ..	238	27 49·0	27 23·7	·8507	+24·6	+16·7	+16·4
28	73 M	Būd Būd B.M. ..	177	23 56·2	33 17·5	·8613	+33·8	+27·7	+27·5
29	73 M	Kulgaria B.M. ..	119	18 11·4	45 15·7	·8228	− 4·0	− 7·9	− 8·2
30	73 M	Burdwān S.B.M.	98	23 14 18·3	87 52 16·9	978·8050	−19·5	−22·8	−23·0
		Mean with regard to sign ..				..	+20·7	+12·3	+12·5
		Mean without regard to sign ..				..	24·7	18·9	19·0

* Topographical reduction up to zone O.

Rānīganj Area

FORD FORMULA					INTERNATIONAL FORMULA				
Hayford's Compensation 113·7 km.	HEISKANEN'S REGIONAL COMPENSATION				Hayford's 113·7 km.	HEISKANEN'S			
	40 km.	60 km.	80 km.	100 km.		40 km.	60 km.	80 km.	100 km.
mgals	*mgals*	*mgals*	*mgals*	*mgals*	*mgals*	*mgals*	*mgals*	*mgals*	*mgals*
+15·4	+14·2	+16·7	+18·9	+20·7	− 2·0	− 3·2	− 0·7	+ 1·5	+ 3·3
+42·0	+40·5	+42·6	+44·6	+46·4	+24·6	+23·1	+25·2	+27·2	+29·0
+36·8	+35·2	+38·3	+40·6	+42·5	+19·4	+17·8	+20·9	+23·2	+25·1
+32·1	+30·8	+33·1	+35·2	+37·1	+14·7	+13·4	+15·7	+17·8	+19·7
+31·7	+30·4	+33·1	+35·7	+37·8	+14·3	+13·0	+15·7	+18·3	+20·4
+18·4	+16·9	+19·8	+22·4	+24·3	+ 1·0	− 0·5	+ 2·4	+ 5·0	+ 6·9
+13·7	+12·2	+14·8	+16·9	+18·7	− 3·7	− 5·2	− 2·6	− 0·5	+ 1·3
+47·2	+45·7	+48·6	+51·0	+52·7	+29·8	+28·3	+31·2	+33·6	+35·3
+43·8	+42·1	+45·1	+47·8	+49·9	+26·4	+24·7	+27·7	+30·4	+32·5
+26·6	+25·0	+28·1	+30·8	+33·0	+ 9·2	+ 7·6	+10·7	+13·4	+15·6
+44·6	+42·7	+46·1	+48·9	+51·1	+27·2	+25·3	+28·7	+31·5	+33·7
+38·3	+37·0	+39·4	+41·3	+43·2	+20·9	+19·6	+22·0	+23·9	+25·8
+35·2	+34·2	+36·7	+38·9	+40·5	+17·8	+16·8	+19·3	+21·5	+23·1
+52·5	+50·8	+54·2	+57·1	+59·6	+35·1	+33·4	+36·8	+39·7	+42·2
− 4·3	− 6·0	− 3·0	− 0·4	+ 1·9	−21·7	−23·4	−20·4	−17·8	−15·5
+53·2	+51·3	+54·7	+57·6	+60·1	+35·8	+33·9	+37·3	+40·2	+42·7
+48·3	+46·6	+49·8	+52·4	+54·7	+30·9	+29·2	+32·4	+35·0	+37·3
+42·7	+40·6	+44·3	+47·3	+49·8	+25·3	+23·2	+26·9	+29·9	+32·4
− 5·6	− 7·5	− 4·3	− 1·5	+ 1·0	−23·0	−24·9	−21·7	−18·9	−16·4
+ 5·3	+ 3·5	+ 6·9	+ 9·8	+12·2	−12·1	−13·9	−10·5	− 7·6	− 5·2
+43·6	+41·4	+45·4	+48·6	+51·5	+26·2	+24·0	+28·0	+31·2	+34·1
+51·2	+49·2	+52·8	+55·8	+58·7	+33·8	+31·8	+35·4	+38·4	+41·3
+52·4	+50·5	+54·1	+57·3	+59·8	+35·0	+33·1	+36·7	+39·9	+42·4
+34·9	+33·2	+36·2	+38·9	+41·2	+17·5	+15·8	+18·8	+21·5	+23·8
+23·8	+22·3	+25·1	+27·4	+29·5	+ 6·4	+ 4·9	+ 7·7	+10·0	+12·1
+28·6	+26·9	+29·8	+32·5	+34·7	+11·2	+ 9·5	+12·4	+15·1	+17·3
+33·7	+32·0	+35·1	+37·8	+40·0	+16·3	+14·6	+17·7	+20·4	+22·6
+43·9	+42·1	+45·1	+47·7	+50·0	+26·5	+24·7	+27·7	+30·3	+32·6
+ 5·7	+ 4·2	+ 7·0	+ 9·5	+11·8	−11·7	−13·2	−10·4	− 7·9	− 5·6
−10·2	−12·0	− 9·0	− 6·3	− 4·0	−27·6	−29·4	−26·4	−23·7	−21·4
+30·8	+29·0	+32·2	+34·8	+37·0					
32·2	30·9	33·3	35·4	37·3					

35. **Magnetic Anomalies in the Rānīganj Area.**—Vertical Force observations were also carried out in conjunction with the gravimeter by means of Variometers Nos. 19134 and 19135. The former was used at the base station and the latter at the field stations. Scale values were checked from time to time and found to be fairly constant.

The magnetic anomalies computed with reference to Rānīganj Standard B.M. are shown in Table 4. These have been corrected for latitude variation which was derived with the help of a generalized V.F. Chart of the earth's magnetic field.

As will be seen the range of anomalies is considerable. Chart XVI shows the V.F. magnetic anomalies with contour intervals of 50γ.

Unfortunately no data is available regarding the magnetic susceptibilities of the rock formations occurring in this area. A systematic investigation of this appears to be necessary.

Some of the salient features of the magnetic anomalies are given below.

The small closed contour of 100γ at the boundary of gneiss and alluvium is unexpected and is possibly due to the boundary being incorrect as this geological map is an enlargement from a very small scale map.

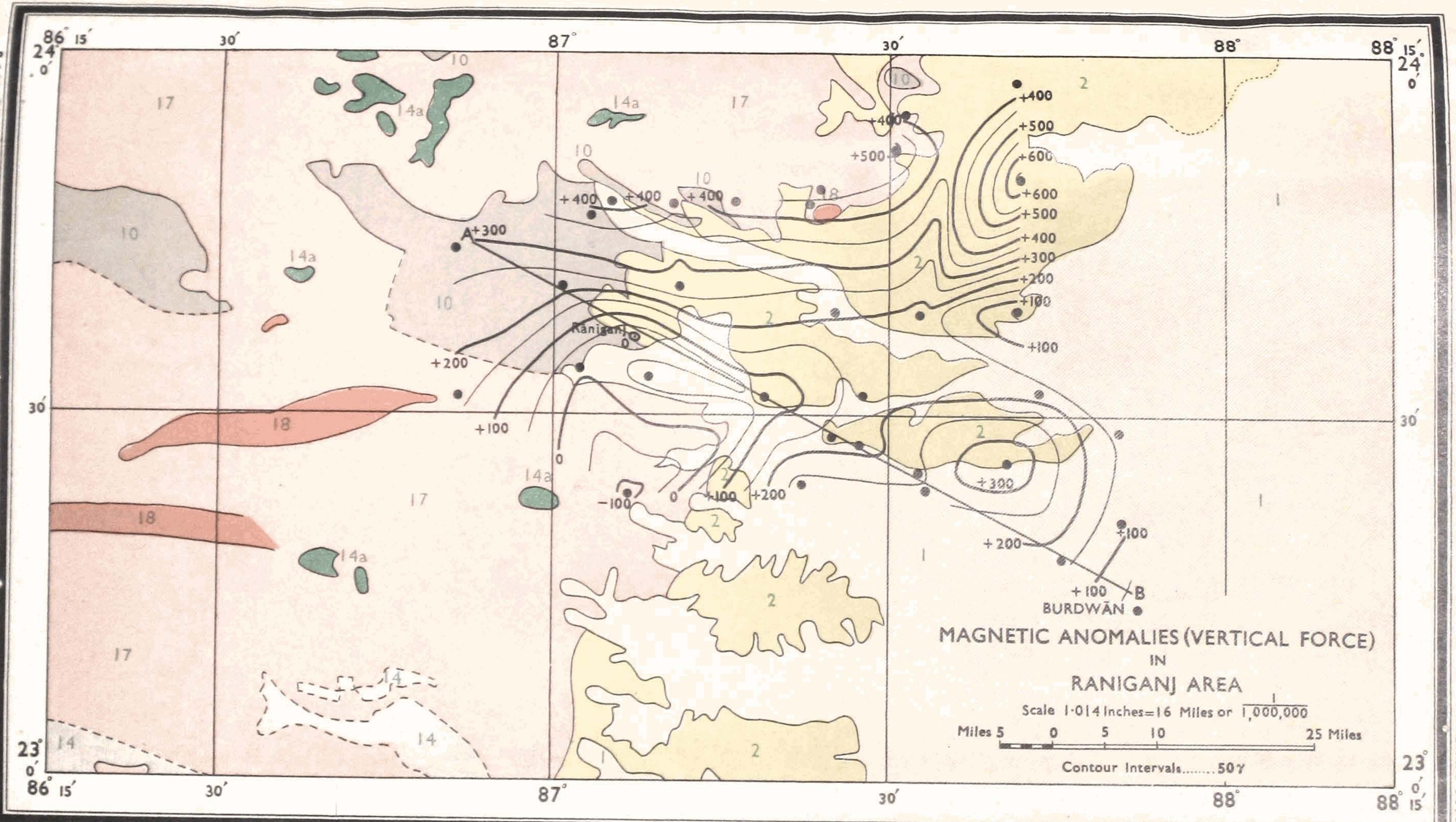
The north-east portion has excessive anomalies and needs further investigation. The pocket on the south-east also is of interest.

The section on line AB is shown in plate ~~XII~~ XVII.

There is a good correspondence between gravity and magnetic maxima near latitude 23° 30′, longitude 87° 30′, but the two are inversely related at the first maximum of gravity just to the SE. of Rānīganj. Magnetic anomalies here exhibit a minimum. It may well mean that the Rānīganj series or coal measures extend up to here only and that the other maximum of gravity and magnetic force (at longitude 87° 30′) is caused by gneisses being humped in the form of a horst or peak under the alluvium. These gneisses are presumably quite magnetic and are responsible for the magnetic high.

It is of interest to note that as in the case of gravity, the steepest magnetic gradients also occur in the neighbourhood of Rānīganj.

Chart XVI



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Older Alluvium, Laterite. 2	Dharwar. 14	Unclassified crystallines, gneiss. . . . 17	Gravity station. . . . . ●

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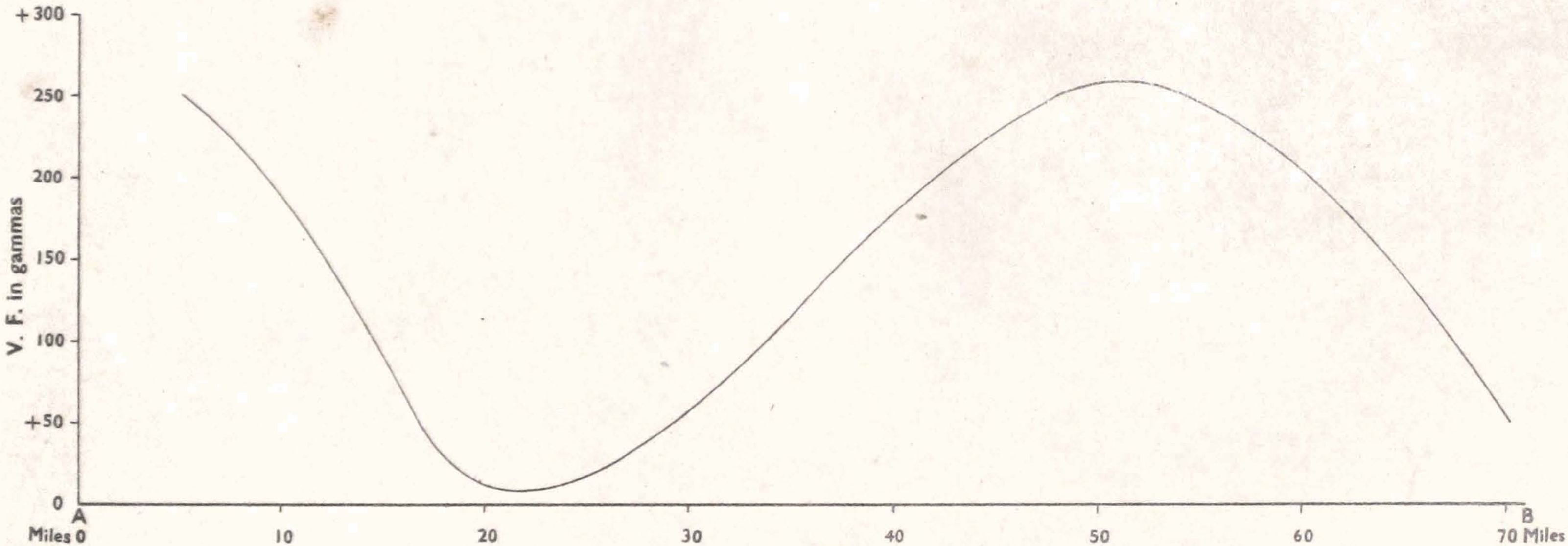
CHART XVII

Magnetic Anomalies (Vertical Force)

Section on A B

Scale 1 Inch=10 Miles



Reg. No. 562 M/N.C. D'50 (G. & T. C. 1"=10 Miles)-375.

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TABLE 4.—*Magnetic Anomalies in Rānīganj Area*

Sheet No.	Station	Latitude	Longitude	Height	Magnetic Anomalies*
		° ′ ″	° ′ ″	*feet*	γ
73 I	G 1 ..	23 43 32	86 50 59	440	+ 279
73 I	G 2 ..	31 37	51 16	659	+ 169
73 M	G 1 ..	47 30	87 05 11	388	+ 446
73 M	G 2 ..	33 47	02 15	341	+ 9
73 M	G 3 ..	40 39	11 04	395	+ 271
73 M	G 4 ..	31 36	18 46	314	+ 58
73 M	G 5 ..	40 19	00 51	307	+ 223
73 M	G 6 ..	33 09	08 36	245	+ 72
73 M	G 7 ..	25 22	32 53	192	+ 230
73 M	G 8 ..	26 12	40 33	162	+ 350
73 M	G 9 ..	38 36	25 02	184	+ 206
73 M	G 10 ..	23 32	06 43	345	+ 113
73 M	G 11 ..	24 05	22 07	191	+ 266
73 M	G 12 ..	38 08	32 51	207	+ 180
73 M	G 13 ..	21 16	50 52	105	+ 112
73 M	G 14 ..	48 32	23 56	257	+ 475
73 M	G 15 ..	47 31	16 19	319	+ 428
73 M	G 16 ..	38 34	41 20	127	+ 44
73 M	G 17 ..	28 46	50 31	122	+ 140
73 M	G 18 ..	31 52	43 32	108	+ 176
73 M	G 19 ..	49 25	41 41	139	+ 660
73 M	G 20 ..	54 50	31 26	260	+ 382
73 M	G 21 ..	51 53	30 34	159	+ 505
73 M	G 22 ..	31 47	27 35	173	+ 166
73 M	Rānīganj S.B.M. ..	36 16	07 06	322	0
73 M	Rānīganj (Magnetic Field Station) ..	35 30	07 30	300	+ 24
73 M	Rājband B.M. ..	28 22	24 37	218	+ 170
73 M	Pānagar B.M. ..	27 49	27 24	238	+ 168
73 M	Būd Būd B.M. ..	23 56	33 18	177	+ 266
73 M	Kulgaria B.M. ..	18 11	45 16	119	+ 172
73 M	Burdwān S.B.M. ..	14 18	52 17	98	+ 13
73 M	Sainthia S.B.M. ..	56 40	40 55	175	+ 360
73 M	Mohanpur B.M. ..	34 07	14 22	260	+ 42
73 M	Dubrajpur (Auxiliary Point) ..	47 14	22 30	..	+ 415
73 M	Mejia (Auxiliary Point) ..	34 04	06 57	..	+ 74
73 M	Purandarpur (Auxiliary Point) ..	51 10	35 22	..	+ 372
73 M	G 24 ..	46 09	03 22	..	+ 379
73 M	G 25 ..	23 47 31	87 10 38	..	+ 363

* With respect to Rānīganj.

36. **Gravity inside the earth.**—The vertical gradient of gravity plays a very important role in Geodesy, but its determination hitherto by means of sensitive balances has been most difficult and not very precise. The modern gravimeters are ideal for the purpose both as regards speed and accuracy and the following proposal was accepted at the Eighth General Meeting of the International Union of Geodesy and Geophysics in Oslo, 1948. "The Association of Geodesy calls attention to the known variability of the vertical gradient of gravity and expresses the hope that it may be studied with the aid of recently developed sensitive gravimeters". In Chapter VII are described the magnetic observations that were undertaken in the Kolar Gold-fields, Mysore, to provide an experimental test of the theories about the magnetic field of the earth. This opportunity was utilized to combine gravimeter observations with the magnetic ones at various levels in the Nundydroog Gold Mines to get an idea of the variation of gravity with depth. The results are as follows :—

Depth below surface *feet*	Δg *mgals*	$\delta g/\delta z$ *mgals per foot*
872	16·2	0·01858
1750	34·6	0·01977
2768	56·3	0·02034
4199	85·6	0·02039

The data for heights underground was supplied by the Chief Surveyor, Nundydroog mine and is quite reliable. In 1907–08, observations had been taken with the pendulum apparatus at the surface and at a depth of 2,628 feet in Edgar Shaft and the following result was obtained :—

Depth below surface *feet*	Change in gravity *mgals*	$\delta g/\delta z$ *mgals per foot*
2628	57·0	0·02131

This agrees more or less with the present findings. The vertical gradient in this area ranges from 0·0185 to 0·0204 mgals per foot. For comparison, it may be noted that the Free-Air gradient is 0·1 mgals per foot and Bouguer gradient is 0·06 mgals per foot on the assumption of ρ (density) = 2·67.

If the earth be considered as a sphere composed of shells of uniform density, gravity at a depth z is $g_z = g_0\ (1 + z/r)$, where g_0 is gravity at the surface

$$\frac{\delta g}{\delta z} = \frac{g_0}{r} = \frac{978}{3960 \times 5280} = 0{\cdot}0465 \text{ mgals per foot.}$$

This is about double of what is actually found, but it is of only theoretical interest as it is well known that the earth is not constituted in this way.

The observed value is very much less than the Free-Air and the usually adopted Bouguer corrections, which may partly be due to the fact that there are very heavy surface rocks at Kolar which exert a greater upward effect as we go down, thus diminishing the vertical gradient.

The above figures are useful in that they give a quantitative idea of the uncertainties with which the usual gravity reductions are burdened and in which for want of better data, the normal value of gravity gradient is used.

The increments of gravity with depth as given in the above table can serve another useful purpose also. They can be used to give the average density of the various layers to different depths in this region.

The Kolar Gold-fields are located in a schist belt composed of ancient basic lavas. There are hornblendic rocks and slates, quartzite and conglomerates. In this area of igneous rocks and sediments, there are numerous auriferous quartz veins. This main mass of hornblendic schist is surrounded by a wide expanse of granitic material. In such a complex series, it is not possible to get a direct determination of the average specific gravity from a few samples. The porosity of rocks, cracks, water content, etc., introduce further uncertainties. The hornblendic schist samples up to a depth of about 3,000 feet have been found to be very uniform and have revealed a density of about 3·013.

If ρ denotes the average density of a strata between the surface and depth z and g_z, g the gravity at the surface and this depth respectively, then $g_z = g + 2gz/R - 4\pi k\rho z$, where k is the gravitation constant.

Substituting in this formula, the gravity increases at various depths from our observations, we get the following figures :—

Layer	Mean density
0 — 972 feet	2·954
0 — 1750 ,,	2·906
0 — 2768 ,,	2·883
0 — 4199 ,,	2·881

These are quite plausible figures. The formula above is approximate in that it assumes normal Free-Air value for vertical gradient and the orographical correction is neglected in the last term. But further refinements are not justified, considering the object in hand.

37. **Old Pendulum Stations.**—Table 5 shows the old pendulum stations connected so far by the gravimeter. These comprise 16 stations on Dehra Dūn–Mussoorie, Dehra Dūn–Simla and Dehra Dūn–Delhi roads ; 2 stations in West Bengal ; 3 in Madhya Pradesh and 2 in South India. The discrepancies between the gravimeter and the pendulum results are tabulated in the last two columns using 0·0809 and 0·0817 for the value of the meter factor respectively. With the exception of 3 stations, the agreement is within the errors of pendulum observations.

TABLE 5.—*Gravity values—Pendulum and Frost Gravimeter*

Serial No.	No. of pendulum station	Sheet No.	Name of Station	Height	Latitude	Longitude	Years of observation	Pendulum value	Gravimeter value	Pendulum *minus* Gravimeter (Factor 0·0809)	Pendulum *minus* Gravimeter (Factor 0·0817)	REMARKS
I				*feet*	° ′ ″	° ′ ″		*gals*	*gals*	*mgals*	*mgals*	
1	1	53 J	Dehra Dūn ..	2239	30 19 29	78 03 22	..	979·063	..	..	..	Base station.
2	39	53 J	Rājpur ..	3321	30 24 02	78 05 07	1929, 1947	979·002	979·0036	— 1·6	— 1·0	Probable position of pendulum station.
3	4	53 J	Dunseverick (Mussoorie) ..	7129	30 27 28	78 03 33	1904, 1948	978·776	978·7791	— 3·1	— 0·3	Exact position.
4	5	53 J	Camel's back (Mussoorie) ..	6921	30 27 35	78 04 32	1904, 1948	978·793	978·7945	— 1·5	+ 1·2	Pendulum station does not exist. Observations at approximate position.
5	184	53 F	Chakrāta ..	6933	30 41 58	77 52 10	1929, 1947	978·819	978·8257	— 6·7	— 4·4	Approximate position.
6	30	53 G	Roorkee ..	867	29 52 20	77 53 59	1906, 1947	979·129	979·1283	+ 0·7	+ 0·1	Exact position.
7	31	53 G	Nojli ..	879	29 53 28	77 40 25	1906, 1947	979·143	979·1412	+ 1·8	+ 1·0	Exact position.
8	37	53 F	Fatehpur ..	1434*	30 25 53	77 43 37	1907, 1947	979·147	979·1449	+ 2·1	+ 1·3	Exact position.
9	38	53 F	Kālsi ..	1684	30 31 08	77 50 26	1907, 1947	979·131	979·1290	+ 2·0	+ 1·3	Exact position.
10	35	53 F	Mohan ..	1660	30 10 53	77 54 37	1907, 1947	979·109	979·1082	+ 0·8	+ 0·4	Exact position.
11	29	53 K	Hardwār ..	949	29 56 29	78 09 19	1906, 1947	979·122	979·1229	— 0·9	— 1·5	Exact position.
12	227	53 B	Ambāla ..	888	30 20 13	76 50 00	1931, 1948	979·200	979·2001	— 0·1	— 1·4	Approximate position.
13	17	53 B	Kālka ..	2202	30 50 08	76 56 22	1905, 1948	979·147	979·1454	+ 1·6	+ 0·8	Exact position.
14	16	53 E	Simla ..	7043	31 06 19	77 09 50	1905, 1948	978·840	978·8432	— 3·2	— 1·0	Exact position.
15	33	53 G	Meerut ..	734	29 00 26	77 41 40	1907, 1949	979·151	979·1508	+ 0·2	— 0·7	Exact position.
16	376	53 H	Delhi ..	715	28 41 21	77 12 53	1935–36, 1949	979·146	979·1456	+ 0·4	— 0·4	Exact position.

* Approximate height. Others are spirit-levelled heights.

TABLE 5.—*Gravity values—Pendulum and Frost Gravimeter*—(concld.)

Serial No.	No. of pendulum station	Sheet No.	Name of Station	Height	Latitude	Longitude	Years of observation	Pendulum value	Gravimeter value	Pendulum *minus* Gravimeter (Factor 0·0809)	Pendulum *minus* Gravimeter (Factor 0·0817)	REMARKS
				feet	° ′ ″	° ′ ″		*gals.*	*gals.*	*mgals*	*mgals*	
II												
17	40	57 G	Bangalore ..	3118	13 00 41	77 35 01	1908, 1948	978·026	..	..	..	In terms of Bangalore (978·026) as datum.
18	42	57 L	Edgar Shaft surface (Mysore) ..	2945*	12 55 47	78 15 41	1908, 1948	978·076	978·0706	+ 5·4	+ 5·0	Approximate position.
III												
19	67	55 F	Seoni ..	2032	22 05 29	77 29 ..	1910, 1948	978·622	..	..	..	Base station.
20	66	64 C	Amgaon ..	1032	21 21 31	80 28 ..	1910, 1948	978·614	978·6134	+ 0·6	+ 0·7	Exact position.
21	237	55 O	Nāgpur ..	1019	21 09 18	79 03 42	1931, 1948	978·611	978·6147	− 3·7	− 3·6	Approximate position.
IV												
22	257	73 I	Dhānbād ..	761	23 48 08	86 25 40	1932, 1947	978·815	..	..	..	Base station.
23	256	73 M	Sūri ..	264	23 54 42	87 31 36	1932, 1947	978·896	978·8944	+ 1·6	+ 0·8	Exact position.

* Approximate height. Others are spirit-levelled heights.

38. **Value of Gravity at Dehra Dūn.**—The first attempt at obtaining the absolute value of gravity at Dehra Dūn was made in 1903–04, when observations were made both at Dehra Dūn and Kew with Von Sterneck's new pendulum apparatus. The value of gravity at Kew was based on Potsdam, which is the reference station for the whole world. The value obtained from 1904 observations for Dehra Dūn was 979·063 cm/sec^2 but it was considered to be suspect as the apparatus was new and the observations both at Kew and Dehra Dūn were not regarded as very satisfactory—at Kew on account of clock trouble and at Dehra Dūn on account of the room in which pendulums were swung having an iron roofing producing very unsatisfactory temperature conditions during the day time. In later years, several attempts were made to connect Dehra Dūn directly and indirectly with some European stations, but as the table below will show, each time a different value was obtained and it was not considered advisable to change the provisionally accepted value. The position was thus unsatisfactory in that Dehra Dūn was not tied so well to the European reference stations as these latter were with respect to one another.

Lately, indirect evidence has revealed that the value of gravity $g = 981 \cdot 274$ cm/sec^2 accepted for Potsdam as a result of very elaborate observations by Kühnen and Furtwängler in the beginning of this century and which was taken as a datum value for the world was really in error by a large amount. Besides, the gravity values at the reference stations of some countries were either not well determined or not known at all and the advent of the modern gravimeter with its extraordinary accuracy and speed of operation offered a unique opportunity to interconnect the various reference stations of the world. Dr. G. P. Woollard of the Oceanographic Institution, Woods Hole, Massachusets in September-November 1948 was able to effect this with a special gravimeter, travelling in a military plane placed at his disposal by the Naval Research Office, U.S.A.

During this extensive world girdling tour which covered a mileage of 83,000 miles he observed at Calcutta, Gaya, Allahābād, Kānpur and five stations in Delhi. None of these stations is an old Pendulum Station of the Survey of India. Dr. Woollard was pressed for time and could not include Dehra Dūn in his itinerary as it is not possible to get there by aeroplane. Accordingly, connection between Dehra Dūn and Dr. Woollard's stations at Delhi was established by the Survey of India with the Frost Gravimeter. These stations were also connected by spirit-levelling and their heights were supplied to Woollard for incorporation in his final report. Table 6 gives the results of the connection.

The values in this table for the Frost Gravimeter are derived from the accepted value of gravity at Dehra Dūn as 979·063. The agreement with Dr. Woollard's values is fairly satisfactory, indicating that the accepted value at Dehra Dūn in old Potsdam terms is practically correct.

Below are the details of the values of gravity at Dehra Dūn obtained at various times.

		cm/sec²
1904	Lenox Conyngham from Kew (Potsdam Pendulums)	979·063
1905	Hecker from Potsdam via Jalpaiguri (Potsdam Pendulums)	979·065
1906	Alessio from Potsdam via Colāba (Potsdam Pendulums)	979·059
1913	Alessio from Genoa (Italian Pendulums) ..	979·079
1924	Cowie from Kew (Potsdam Pendulums) ..	979·054
1927	Glennie from Cambridge (Cambridge Apparatus) ..	979·072
1929	Glennie & Cowie from Kew (Potsdam Pendulums)	979·068
1929	Spoleto from Genoa (Italian Pendulums) ..	979·069
1929	Vening Meinesz from de Bilt via Colombo ..	979·075
1932	Lejay from Potsdam via Colombo	979·085
1939	Brown & Glennie from Cambridge (Cambridge Apparatus)	979·056
1948	Woollard & Gulatee from Washington via Delhi (Worden & Frost Gravimeters)	979·063

Gravimeters are normally meant for local use and this is the first time that one has been utilized for geodetic purposes. Slight errors in meter calibration factor while not so important for limited areas produce significant errors when the gravity range covered is large. The latest value obtained with the help of the Frost and Worden gravimeters is smaller than what was expected from other considerations. Dr. Woollard is now planning to repeat and extend his observations with two instruments shortly and the value at Dehra Dūn will then be finalized.

The absolute value of gravity at all Indian stations will need a change when the corrected Potsdam value is adopted universally, but the chart of gravity anomalies will remain unaffected.

39. **Gravimeter Stations near Dehra Dūn.**—Table 7 shows the anomalies at 28 stations reported provisionally in Technical Report, 1947, Part III. These stations were really observed to test the working and the capabilities of the Frost Gravimeter and at the time of writing the Report, the co-ordinates and heights of these stations were not available. This deficiency has now been made up and the gravity anomalies also have been worked out and are included in the table.

No unusual anomalies are indicated.

40. **Siamese Gravity Stations.**—Gravity data for 17 stations in Siam has been obtained from the Royal Survey Department of Siam. Isostatic reductions for these stations have been made in the Computing Office at Dehra Dūn and are given in Table 8.

These values have been used to revise and extend the existing charts of gravity anomalies on the Helmert and International spheriods (see Charts XI and XII). A comparison with the older charts will reveal that this additional evidence has resulted in material change in the picture of the anomalies in this region, The older contours in the area between Andaman Islands and Mergui were based on very conjectural data and these Siamese stations are consequently of considerable value.

The main feature disclosed by this additional information on the Helmert spheroid is the intrusion of the negative anomaly area in about the latitude of 14° N. separating two regions of positive anomalies. On the International spheroid the anomalies are now predominantly negative in contrast to the positive ones shown on previous charts. The negative strip to the west joining on with the negative strip of Vening Meinesz in the neighbourhood of Sumatra remains intact.

TABLE 6.—*Dr. Woollard's Gravimetric Stations in India*

Place	Date	Latitude	Longitude	Height above mean sea-level	Value of *g* by Frost gravimeter	Value of *g* by Worden gravimeter	REMARKS
		° ′ ″	° ′ ″	*feet*	*cm/sec²*	*cm/sec²*	
Willingdon Air Port, New Delhi ..	28 Jan. 1949	28 35 00	77 12 43	693	979·1359	979·1352	At entrance to terminal building on ground level.
Imperial Hotel, New Delhi	29 Jan. 1949	28 37 31	77 13 08	695	·1363	·1364	On ground level in Queensway, New Delhi.
Surveyor General's Office, Delhi ..	28 Jan. 1949	28 41 08	77 13 30	701	·1456	·1459	Old Secretariat, Delhi.
Palam Road Junction, New Delhi ..	29 Jan. 1949	28 35 30	77 09 42	799	·1317	·1320	Junction of station and Gurgaon roads.
*Palam Air Port, New Delhi ..	..	28 35	77 07	720	979·1321	979·1424	On landing strip just outside field entrance to terminal building.
*Dum Dum Air Port, Calcutta ..	..	22 38	88 26	14	Not available	978·8062	These stations are not yet connected by Frost Gravimeter.
*Gaya Air Port ..	..	24 44	84 57	370	„	·8811	
*Allahābād Air Port ..	..	25 27	81 44	319	„	·9446	
*Kānpur Air Port ..	..	26 24	80 25	410	„	978·9761	

* Precise elevations and positions of these stations are not known, as they are not connected by spirit-levelling and large scale maps for them are not available. The positions and heights are estimated values, and are approximate only.

TABLE 7.—*Gravimeter Stations near Dehra Dūn*

Serial No.	Sheet No.	Station	Date	Height	Latitude	Longitude	g	$g-\gamma_A$	$g-\gamma_B$	$g-\gamma_0$
				feet	° ′ ″	° ′ ″	cm/sec²	cm/sec²	cm/sec²	cm/sec²
1	53 J	Dehra Dūn ..	15 4 47	2239	30 19 29	78 03 22	979·063	−·074	−·145	+·006
2	53 F	Asareri ..	16 4 47	2310	30 14 18	77 58 36	979·067	−·058	−·134	+·012
3	53 F	Mohan ..	18 4 47	1660	30 10 53	77 54 37	979·109	−·074	−·124	+·002
4	53 F	Mohan Auxiliary ..	17 4 47	1486	30 10 44	77 54 38	979·116	−·080	−·128	−·002
5	53 F	Fatehpur ..	18 4 47 5 5 47	985	30 02 46	77 45 46	979·134	−·099	−·131	−·025
6	53 G	Roorkee ..	19 4 47	867	29 52 20	77 53 59	979·120	−·102	−·129	−·045
7	53 K	Rānipur ..	19 4 47	942	29 55 12	78 04 54	979·116	−·111	−·143	−·031
8	53 K	Hardwār ..	20 4 47	949	29 56 29	78 09 19	979·122	−·105	−·135	−·016
9	53 J	Raiwāla ..	20 4 47	1179	30 01 58	78 12 50	979·107	−·107	−·069	−·018
10	53 J	Kansrao ..	20 4 47	1334	30 04 55	78 08 32	979·106	−·097	−·141	−·012
11	53 J	Lachchīwāla ..	22 4 47	1685	30 11 51	78 07 42	979·087	−·092	−·092	−·005
12	53 G	Sahāranpur ..	5 5 47	902	29 57 27	77 33 27	979·158	−·075	−·105	−·021
13	53 F	Fatehpur I.B. ..	5 5 47	1434	30 25 53	77 43 37	979·147	−·076	−·121	+·017
14	53 G	Nojli ..	13 5 47	879	29 53 28	77 40 25	979·143	−·090	−·119	−·031
15	53 F	Sahaspur ..	15 5 47	1605	30 23 21	77 49 00	979·127	−·075	−·126	+·023
16	53 F	Kālsi I.B. ..	16 5 47	1684	30 31 08	77 50 26	979·131	−·075	−·122	+·031
17	53 F	Kālsi B.M. 341 ..	16 5 47	1716	30 31 17	77 50 43	979·126	−·075	−·123	+·033
18	53 F	Culvert between furlong-stones 54/5 and 54/6 ..	17 5 47	2573	30 32 32	77 50 39	979·079	−·044	−·121	+·044
19	53 F	B.M. 347 ..	17 5 47	2962	30 33 54	77 51 07	979·058	−·030	−·114	+·059
20	53 F	B.M. 351 ..	17 5 47	3438	30 36 49	77 52 37	979·032	−·016	−·117	+·065
21	53 F	Bridge furlong-stone 64/4) ..	20 5 47	4037	30 37 58	77 52 40	978·999	+·006	−·118	+·068
22	53 F	B.M. 357 ..	20 5 47	4587	30 38 29	77 51 36	978·970	+·028	−·118	+·068
23	53 F	B.M. 360 ..	20 5 47	5232	30 39 46	77 51 33	978·934	+·050	−·118	+·071
24	53 F	B.M. 363 ..	20 5 47	5832	30 40 30	77 52 23	978·895	+·066	−·119	+·073
25	53 F	B.M. 366 ..	20 5 47	6655	30 41 19	77 52 12	978·842	+·090	−·120	+·073
26	53 F	Chakrāta I.B. ..	20 5 47	6933	30 41 58	77 52 10	978·819	+·103	−·118	+·073
27	53 F	Furlong-stone 76/4 ..	20 5 47	6744	30 41 36	77 52 29	978·838	+·093	−·121	+·073
28	53 F	B.M. 377 ..	21 5 47	7217	..	..	978·809		..	..

TABLE 8.—*Siamese Gravity Stations*

Serial No.	Sheet No.	Name of Station	Date	Height in metres	Latitude N.	Longitude E.	g	$g-\gamma_A$	$g-\gamma_B$	$g-\gamma_{CH}$	$g-\gamma_{CI}$
					° ′	° ′	cm/sec^2	cm/sec^2	cm/sec^2	cm/sec^2	cm/sec^2
1	D-47 Q	Kromphaeuthi ..	1937–38	3·7	13 45·1	100 29·6	978·310	−·011	−·011	−·008	−·026
2	E-47 J	Doi Khunkong ..	1938	669·5	18 27·5	99 30·0	978·361	+·019	−·051	−·003	−·021
3	E-47 J	Wat Walakaram ..	1938	233·4	18 17·5	99 29·6	978·438	−·029	−·054	−·012	−·030
4	E-47 J	Ban Pannua ..	1938	297·3	18 48·8	99 54·5	978·437	−·038	−·070	−·021	−·039
5	E-47 D	Wat Ngammuang ..	1938	418·7	19 54·7	99 49·5	978·522	+·023	−·022	+·042	+·024
6	E-47 Q	Wat Sanyaphong ..	1938	74·9	17 37·4	100 05·2	978·472	−·008	−·016	+·010	−·008
7	E-47 W	Wat Phrasirattanamahathat ..	1938	45·6	16 49·3	100 15·7	978·473	+·025	+·020	+·037	+·019
8	E-47 W	Bangmunnak ..	1938	31·1	16 01·9	100 22·9	978·415	+·001	−·002	+·011	−·007
9	B-47 L	Samnak Phutthaphum ..	1939	18·3	6 33·5	101 17·4	978·098	+·006	+·004	+·004	−·015
10	B-47 E	Wat Saket ..	1939	5·0	7 12·3	100 35·7	978·137	+·027	+·027	+·022	+·003
11	C-47 V	Wat Phraboromthat ..	1939	5·7	8 24·8	99 57·8	978·150	+·012	+·012	+·010	−·009
12	B-47 D	Wat Trangkhaphumphutthawat	1939	6·0	7 24·6	99 31·5	978·151	+·037	+·037	+·031	+·012
13	C-47 P	Wat Wiangchaiya ..	1939	6·8	9 23·1	99 11·2	978·209	+·044	+·044	+·038	+·019
14	C-47 J	Wat Thataphao Nua ..	1939	4·9	10 30·1	99 10·0	978·202	+·002	+·002	−·003	−·022
15	C-47 D	Wat Khaobot ..	1939	4·6	11 13·0	99 30·4	978·230	+·006	+·006	+·003	−·016
16	D-47 V	Wat Pakkhlongran ..	1939	4·7	12 23·9	99 59·4	978·285	+·018	+·018	+·018	−·000
17	D-47 P	Wat Pom ..	1939	6·0	13 06·0	99 56·9	978·295	+·002	+·002	+·004	−·015
18	D-47 P	Wat Suwannaram ..	1939	26·9	13 59·3	99 33·9	978·313	−·011	−·013	−·004	−·023

41. **Average Height Map.**—Chart XVIII shows the average height map of India which is drawn by estimating the average heights of $\frac{1}{2}°$ squares. This was drawn in the main by Col. Glennie with extensions northwards and eastwards by Mr. Hashmie. This chart has been found very useful for computing the Isostatic reduction for zones 12 to P. For zones N and O certain care is needed if these cut very high contours.

CHAPTER IV

DEVIATION OF THE VERTICAL

BY B. L. GULATEE, M.A. (CANTAB.)

SECTION I.—FIELD SEASON, 1947–48

42. **Summary.**—Both components of the deviation of the vertical were measured with an astrolabe at 2 stations in Mārwār, 12 stations in South India and 1 station in Nepāl.

Observations to Polaris were also taken for the determination of azimuth at 2 stations in Mārwār, 2 stations in South India and one station in Nepāl. The first two stations were observed for comparison with the 1945–46 and 1946–47 values observed with Shutter theodolite. The azimuth observations at the two astrolabe stations in South India and one in Nepāl were undertaken to make them into Laplace stations for azimuth control of the triangulation series to which they belong. The astrolabe observations at the 12 stations (about 15 miles apart) in South India including the two Laplace stations mentioned above were made with a view to obtaining a reliable section of the geoid in this area.

43. **Observations.**—The instruments used were the big astrolabe, Two-Pen Mercer Chronograph, Mercer break-circuit Chronometer and Marconi Wireless receiver.

The instants of the passages of the stars through the altitude of 60° were recorded by one pen of chronograph and were read with the help of a time scale provided by the other pen beating seconds of the chronometer.

Wireless rhythmic signals were received from Rugby at 9:55 and 17:55 hours G.M.T. The chronometer is so arranged as to disable the wireless set for a fraction of a second every second, so that about one third of the pips are obscured. The times of the first signals to emerge from the silence are recorded on the chronograph and from them the Greenwich Sidereal Time error of the chronometer is derived. The required longitude is then obtained by subtracting from it the Local Sidereal Time error as determined from stellar observations with the astrolabe. These longitudes have been corrected for emission corrections received from the Royal Observatory, Greenwich.

One night's work was normally done at each station.

44. **Personal Equation.**—Observations to measure the personal equation of the observer were made for two nights at Dehra Dūn, one night at Bangalore, and two nights before and two nights after the field work in South India at old Madras Longitude station. The wireless receiver broke down in Nepāl and consequently observations for personal equation could not be made at Dehra Dūn

after the close of the field work. This is not serious in view of the consistency of the measurements obtained from time to time at different places during the season.

The figures obtained for personal equation were as follows :—

Dehra Dūn		Madras		Madras	
	s		s		s
Nov. 2 ..	+ 0·13	Dec. 2 ..	+ 0·19	Jan. 21 ..	+ 0·25
Nov. 7 ..	+ 0·23	Dec. 11 ..	+ 0·10	Jan. 22 ..	+ 0·24
		Bangalore			
		Dec. 8 ..	+ 0·19		
Mean ..	+ 0·18	Mean before the commencement of field work in South India	+ 0·16	Mean at the close of the field work in South India ..	+ 0·24

A correction of $+0\cdot17$ seconds was applied to the longitude value of Mārwār station, corrections ranging between $+0^s\cdot16$ and $+0^s\cdot24$ to other stations of South India, and $+0^s\cdot24$ to the last station observed in Nepāl.

45. **Geodetic Positions.**—The astrolabe was placed on old station marks or in their immediate vicinity where these could be reached without much difficulty, and the geodetic position of the astrolabe station was deduced by observing an approximate azimuth and measuring its distance with a tape from the known points. The geodetic position of some stations was determined by theodolite resection from existing trigonometrical stations and points utilizing an astronomical azimuth usually obtained from sun observations. In some cases the astrolabe station formed one end of a measured short base and its geodetic position was determined by observing to a known station or point supported by a sun azimuth.

46. **Narrative.**—One detachment consisting of Mr. J. B. Mathur (Surveyor), one recorder and 10 *khalāsīs* left for Mārwār on 14th November 1947 by train after completing observations for two nights at Dehra Dūn for the determination of personal equation. The detachment reached Erinpura Road R.S. on 17th November and in addition to the normal astronomical programme, observed astronomical azimuths at two stations, Pāwa and Sumerpur.

After completion of work at Mārwār the detachment left for South India and arrived in Madras on 2nd December and observed for personal equation for one night at the old Longitude Station.

The observer then went to Bangalore to arrange for mechanical transport for his detachment and to compile the trigonometrical data required for position fixing of his stations from the office of the

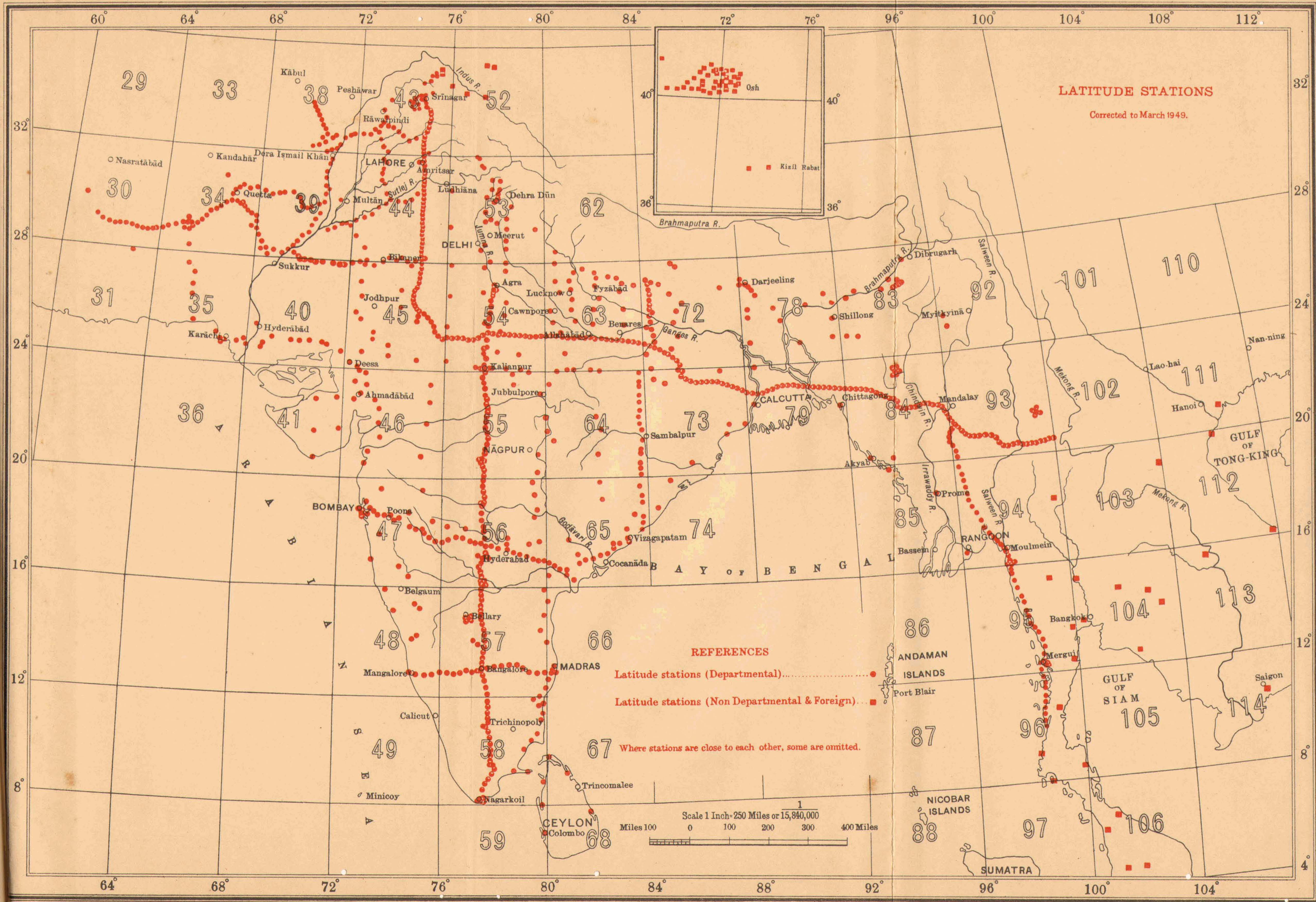

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Chart XX

Reg. No. 126 M/GB. 1936 (C.O.)S.I.-400-410.-38, 425-39, 355-40, 315-44-400'48-375'50.

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Southern Circle, Survey of India. In the course of his visit, he also observed for personal equation at the old Bangalore Longitude Station (1877–88).

On return to Madras, he observed for personal equation for one more night on 11th December and then proceeded with his programme of observations of 12 stations from Madras to Arangatanzi in degree sheet 58 N. These stations were spaced at intervals of about 15 to 20 miles.

It was not possible to arrange for motor transport as the local dealers demanded exorbitant rates. Journeys were performed by train which was of metre gauge and was always very crowded.

The original programme of observations in Nepāl was to establish Laplace stations at Ladnia, Tamarang, Sandakphu and Kātmāndu in order to control the error in bearing of the recent topographical triangulation in Nepāl carried out in connection with the Kosi Project.

After arranging for camp equipment and permits for entry into Nepāl the detachment travelled by lorry from Forbesganj to Chaitra and thence by ferry to Barahakshetra and Tamarang. Observations were made at Tamarang on 7th and 8th February. The wireless set failed after that and was taken to Calcutta for repairs but could not be put into working order. This wireless set could not be replaced as no other set was available. Further work was, therefore, not possible and the detachment consequently returned to Dehra Dūn towards the end of March 1948.

The Marconi R.P. 11 sets which are in use in the Survey of India for reception of Ultra Long-wave signals have become too antiquated and arrangements are being made to replace them by suitable communication receivers for short wave rhythmics.

47. **Results.**—(*a*) *Mārwār Section.* Experimental high precision traverses were run in the Erinpura area of Jodhpur in 1945–46 and 1946–47 to test the method and the technique of observations. A regular and essential feature of the project was to control the geodetic azimuths by observing astronomical azimuths at intervals of about 10 miles and correcting them for deviation of the vertical. The accuracy aimed at for astronomical control was 1″ of arc and the instrument used was a small Tavistock Theodolite equipped with Shutter eye-piece.

On close of the work, it was found that not only were there considerable discrepancies in the values of astronomical longitudes in the two seasons' work for the same stations, but the geodetic azimuths as derived from astronomical ones differed from the trigonometrical azimuths by amounts much greater than the estimated accumulated errors at different stations.

To settle the various points of doubt, it was decided in 1947–48 to reobserve the astronomical azimuths with a Geodetic Wild

Theodolite and to obtain the deflections by Astrolabe at two stations. The results which are given below confirmed the suspicion that the observations with the improvised Shutter Tavistock were unsatisfactory both as regards Longitudes and Azimuths. The errors in the deflections were much greater than their actual magnitude.

Name of Station	Prime Vertical deflections			Geodetic Bearing of reference object		
	1945–46 (Shutter)	1946–47 (Shutter)	1947–48 (Astrolabe)	1946–47 Astro. values reduced to geodetic	1947–48 Astro. values reduced to geodetic	Triangulation values
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	"	"	"	° ′ ″	° ′ ″	° ′ ″
Pāwa ..	+2·7	−7·4	+4·2	134 01 36	134 01 40	134 01 39
Sumerpur..	−6·4	+16·7	+4·5	159 02 23	159 02 42	159 02 36

The actual deflections in this area are small and consequently the difference between astronomical and geodetic azimuths is only 2″.

(*b*) *Observations in South India.*—These observations were undertaken to reduce the closure error of +35 feet in the circuit Bangalore–Madras–Manaar–Minakshi. The new observations have reduced this error to +11 feet.

Opportunity was taken to establish one new Laplace station at Mallipat H.S. of South-East Coast Series, seasons 1875–79 and Villupuram Series of 1911–12, and to check the old Laplace station of St. Thomas's Mount Trestle S. of Madras Longitudinal series of 1865–80. Details of the Laplace corrections derived are given below.

The accepted value of the geodetic azimuth at Mallipat H.S. of Ekkamalai H.S., A_g is 110° 46′ 24″·2. The present observations give the value of astronomical longitude to be $L_a = 79° 22' 28''\cdot 20$ and astronomical azimuth, A_a at Mallipat H.S. of Ekkamalai H.S. to be 110° 46′ 22″·1. The resulting correction to the geodetic azimuth as a result of the Laplace Equation is

$$\delta A_g = A_a - A_g - [\,(L_a - L_g) + 3''\cdot 16\,] \times \sin\lambda_g = -1''\cdot 6$$

The nearest Laplace station to this station is 80 miles away and this correction is not unexpected considering the accuracy of the observations. The astronomical azimuth was obtained by 65 observations to Polaris, the probable error of the resulting mean value being $\pm 0''\cdot 43$.

Observations at St. Thomas's Mount Trestle S. are also interesting and the table below gives the comparison of the old and new values of correction to the published geodetic azimuth :—

Year of observation	Latitude Station	Longitude Station	Azimuth Station	A−G in Lat.	A−G in Long.	Laplace correction =A−G in Azimuth	Correction to published geodetic azimuth
				"	"	"	"
1890	St. Thomas's Mt.	Madras	St. Thomas's Mt.	+5·85	−07·3	+0·9	−3·1
1947	St. Thomas's Mt.	St. Thomas's Mt.	St. Thomas's Mt.	+6·14	−08·5	+1·2	−2·8

The Laplace correction given above in column 7 is the correction which is applied to the observed astronomical azimuth to obtain the correct geodetic azimuth. The last column gives the error accummulated in geodetic azimuth. The older observations for longitude were not made at St. Thomas's Mount but at Madras, and the difference A—G in longitude at Madras was used for the calculation of the corrections to azimuth at St. Thomas's Mount.

The agreement of the derived correction to published geodetic azimuth is satisfactory and within the precision of observations. The older observations were done by much more rigorous methods as they were made at one station only. The present ones are for a different purpose namely the delineation of the geoid. The older latitude in 1890 was obtained by the Talcott method by observations of 39 pairs of stars, its probable error being ± 0″·077. The probable error of the new latitude with the astrolabe is ± 0″·912.

Similarly the older longitude was observed by electro-telegraphic arcs, its p.e. being reckoned as ± 0″·329; that of the new longitude is ± 0″·150.

The older azimuth was derived by observations to 80 circumpolar stars at elongation, the p.e. being ± 0″·134 as against the p.e. of ± 1″·42 of the 1947 observations which was derived from Polaris observations only with a small Wild Theodolite.

(c) *Laplace in Nepāl.*—As has already been mentioned, it was originally intended to observe for Laplace at Ladnia T.S., Tamarang h.s., Sandakphu h.s. and Kātmāndu. Owing to the break down of the wireless set, observations were made at Tamarang h.s. only. Unfortunately this is a station of subsidiary triangulation which is not connected to the main topographical triangulation from Sandakphu to Ladnia. Consequently the geodetic longitude of this station is doubtful and the astronomical observations cannot be utilized for deriving the Prime Vertical deflection and for the correction of triangulated azimuth for Laplace error. The astronomical co-ordinates of this station are latitude 26° 52′ 56″·80 and longitude 87° 11′ 24″·15.

SECTION II—FIELD SEASON 1948–49

48. **Summary.**—Two detachments were formed to determine the deviation of the vertical, one under Mr. O. P. Grover, M.A., assisted by one Surveyor and the other under Mr. J. B. Mathur.

The former was to determine only the meridional component of deflection along longitude 83° 45′ between Waltair and Dehri-on-Sone at 23 stations (including two old latitude stations), the object being to improve the geoidal circuit closure of —30 feet of which this line forms a part. The second detachment determined both components of the deviation of the vertical, and also azimuths at three pairs of stations in Madhya Bhārat for obtaining reliable values of Prime Vertical deflections and corrections to triangulated azimuths. Old values of deflections at these stations had been determined from azimuth observations and appeared to be suspects as they were not in tune with the deflections at the neighbouring stations.

49. **Observations.**—(i) Detachment No. 1, under Mr. O. P. Grover, M.A., observed Astronomical latitudes with Zenith Telescope No. 1 by Messrs. Troughton & Simms (Plate XXI). The values of one division of the micrometer were determined before and after the field season with the following results :—

Before the field season 69″·26 from Polaris at elongation.

After ,, ,, ,, 69″·20 from 6 micro pairs.

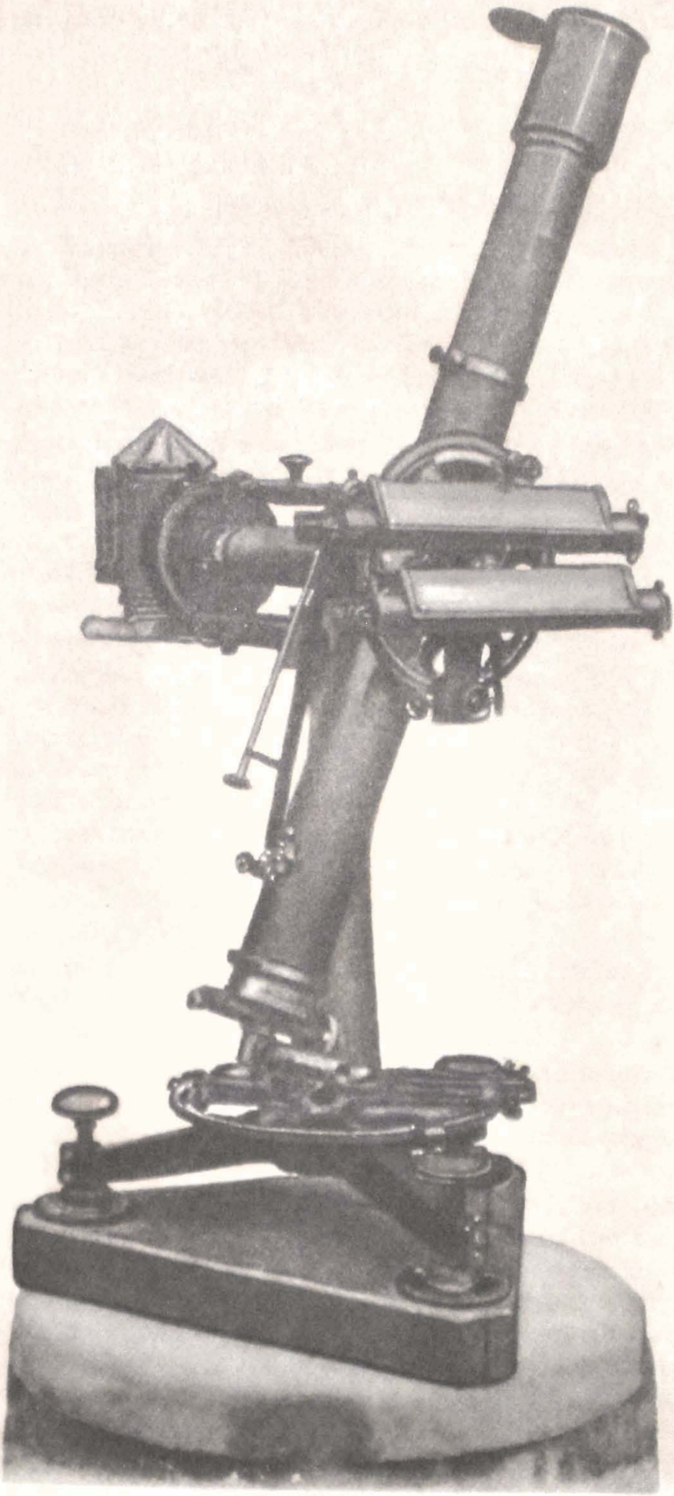
This instrument has been in use for a long time in the department and the earlier values of one division of its micrometer are tabulated below :—

		″
1902–05	..	69·22
1923–25	..	69·16
1930–31	..	69·03
1933–34	..	69·19
1934–35	..	69·15

Before the start of work, the instrument was set in the meridian with the help of Polaris. The actual programme of observations consisted in observations to not less than 8 pairs of latitude stars, 2 collimation stars and 4 time stars each night. One night's work was normally done at each station.

Only one station was fixed by resection. The others were located either at or in the immediate vicinity of previously fixed trigonometrical points.

(ii) Detachment No. 2, under Mr. J. B. Mathur, observed with the astrolabe. One night's work was normally done at each station except at the first station where two nights' were observed on account of the faulty behaviour of the clock. Greenwich time was obtained from the Rugby 09–55 and 17–55 G.M.T. signals. The observations were made at the old sites of the geodetic stations, which were unmistakably identified.



THE ZENITH TELESCOPE.

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50. **Personal Equation.**—Observations were made with the astrolabe at Dehra Dūn by Mr. J. B. Mathur before and after the field with the following results :—

Date		Personal Equation
		s
Mean before field season	..	+0·28
Mean after field season	..	+0·28

These have been corrected for B.H. corrections from Rugby.

51. **Narrative.**—(i) Detachment No. 1 consisting of one observer, one assistant and 15 *khalāsīs* left for Vizianagram on 26th November 1948. The work was started from Rāmchandarpur (District Vizagapatam, Madras). The station is just near the sea-shore and was utilized by the Indian Army for fixing the air-craft guns on it in the last Great War. Transport was difficult and the area was infested with tigers and wild elephants. The health of the detachment remained normally good.

(ii) Detachment No. 2 consisting of one observer, one computer and 12 *khalāsīs* left Dehra Dūn on 3rd January 1949 and arrived at the first station on the 7th January 1949. The work proceeded well except for bad weather and untrained lampsmen who caused a delay of about 2 weeks in the programme.

52. **Laplace Stations in Madhya Bhārat.**—It was noticed that prime vertical deflections at Amua H.S., Rangir S. and Karara H.S. were unduly large. These stations are near the crest of the Hidden Range and are on flat ground. The deflections were derived from azimuth observations and appeared to be suspect as there were no obvious grounds for their being abnormal. To test these, twin Laplace Stations have been established at the former two stations and a single Laplace at Karara H.S. The results are tabulated in Table I.

New observations show that the accepted prime vertical deflection is in error at Rangir by 30″, at Amua by about 6″ and at Karara by about 12″.

The last two columns give the errors accumulated in geodetic azimuth as derived by the new observations and that accepted before for deriving the P.V. deflection from azimuths given in column 8.

It will be seen that whereas the large discrepancy in P.V. deflection at Rangir is due to an error of 13″ in the old astronomical azimuths, the discrepancies at the other two stations arise from a wrong estimation of the error accumulated in geodetic azimuths due to lack of Laplace control. All these stations, although they belong to secondary series of triangulation, are also common to the Calcutta Longitudinal Series, which is of primary quality and the small accumulation of error in geodetic azimuth at Rangir and Amua is reasonable.

At Karara the error in geodetic azimuth is 7·1″ ; this is rather large and needs further investigation.

The new meridional deflections at all the three stations are in satisfactory agreement with the older values.

53. **Deflections in Subansiri Area (Assam).**—To provide Laplace control for the Subansiri (Assam) reconnaissance triangulation in 1944–45, Mr. M. N. Kalappa observed for deflections of the plumb-line at three stations.

The astronomical latitudes and longitudes were obtained by semi-graphical fixing from observations to 4 stars, in four quadrants by position line (intercept method). Astronomical azimuths were derived by observations to sun and are not of a high degree of accuracy.

The datum for co-ordinates of the triangulation is an 'S' class intersected point, the scale is derived from a base measured with a 10-foot subtense bar, and the initial azimuth is a sun azimuth. Another sun azimuth observed at Pad Puttu differs from its triangulated value by 41 seconds. The triangulated values of the co-ordinates of the Laplace stations are therefore weakly determined. The deflections are not thus of a high degree of precision and may be in error by 5″ to 10″. They are included in Table 2 as there are no other deflection stations in the area.

54. **Results.**—Table 2 gives the results of the deflection observations made during the two field seasons 1947–48 and 1948–49. Chart XXII gives the revised geoidal circuits and their closing errors.

The new stations were designed to strengthen the weaker portions of the two circuits Kaliānpur–Waltair–Sambalpur–Allahabād–Kaliānpur in Madhya Pradesh and Bangalore–Minakshi–Madras–Bangalore in South India. As regards the first circuit latitude observations along the meridian of 83° 45′ have improved its closure error by 15 feet but have naturally worsened the closure error of the circuit to the east by the same amount. This latter circuit has one very weak side from Waltair to Calcutta. A few deflection stations on this line are desirable.

While the new closure error of −15 feet in a circuit of linear length of about 1700 miles can be regarded as satisfactory, part of it is no doubt due to the fact that the deflections at some of the new stations display a large variation on account of the rugged topography. Some parts of the area contain hills with elevations of about 4000 feet and the spacing of the stations at 15 to 20 miles is rather large for interpolating the deflections.

The closure error of the circuit in South India has also been appreciably reduced from +35 feet to +11 feet. At the southern tip of the circuit, however, the spacing of three stations is about 50 miles and this is possibly responsible for a part of the residual error of +11 feet.

The charts of the Geoid and the Compensated Geoid in India, Charts XXIII and XXIV, have been revised incorporating the results of the new deflection data. In drawing these charts for the earlier Reports the stronger geoidal sections were treated as errorless

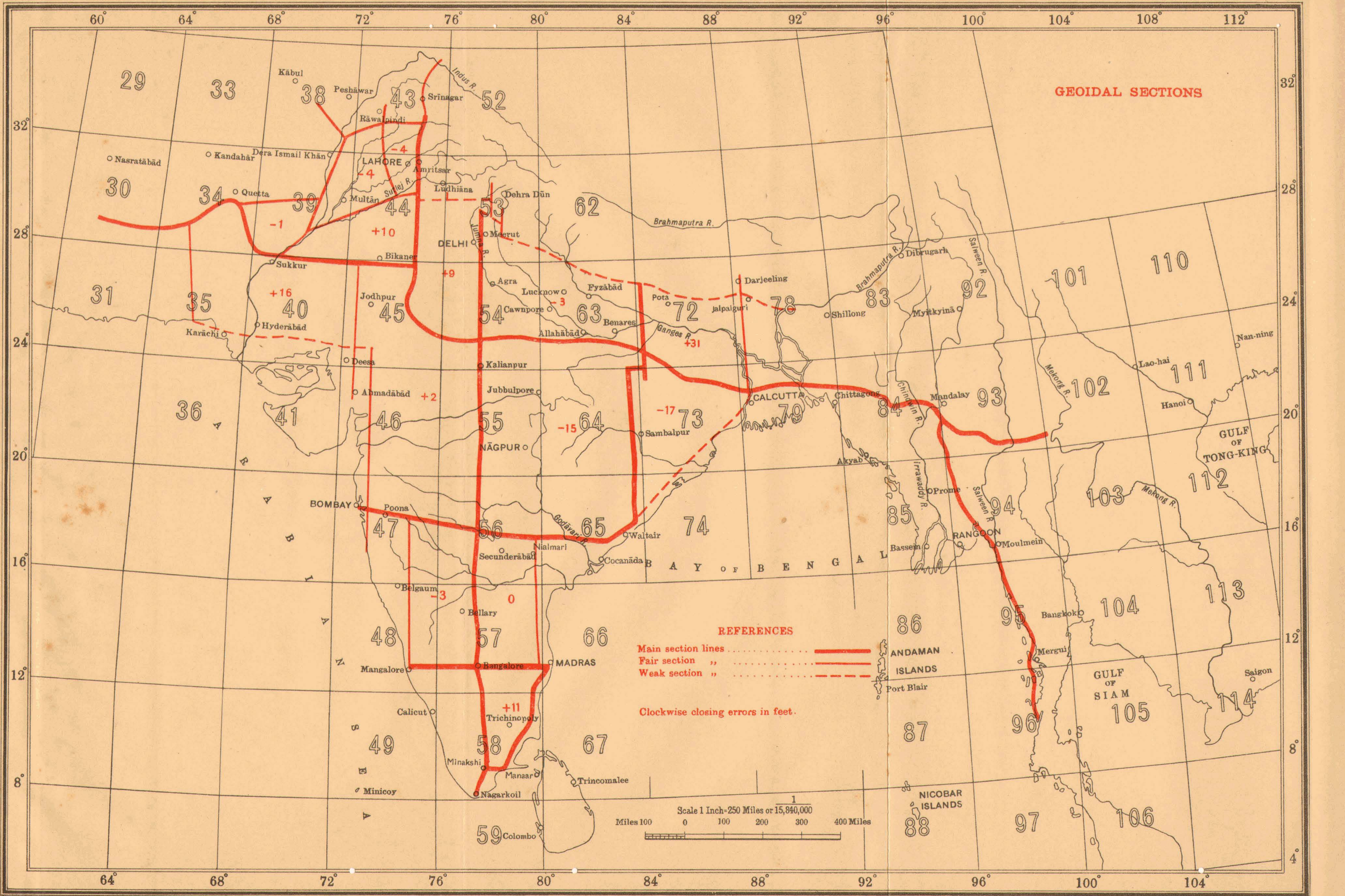

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Chart XXIII

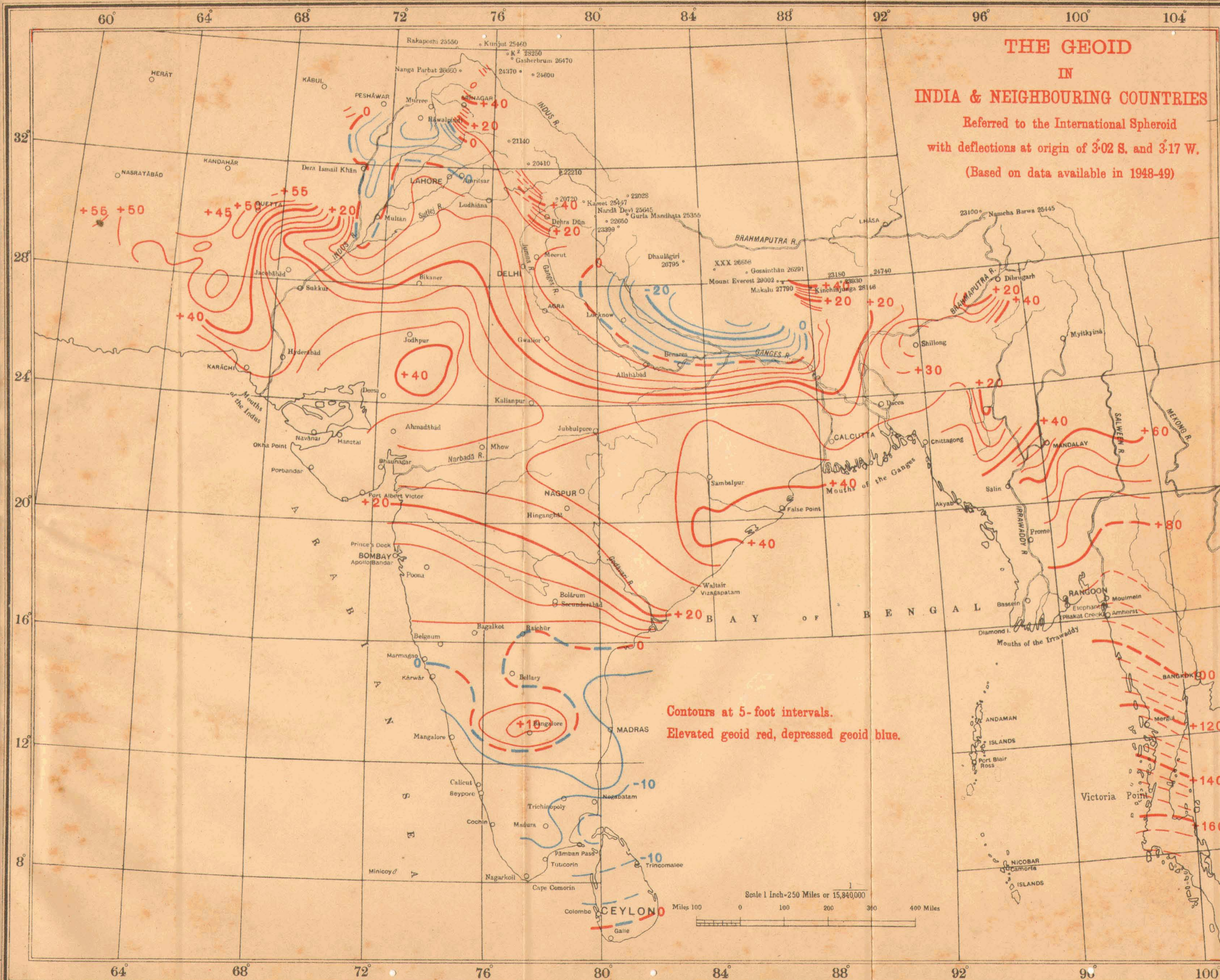

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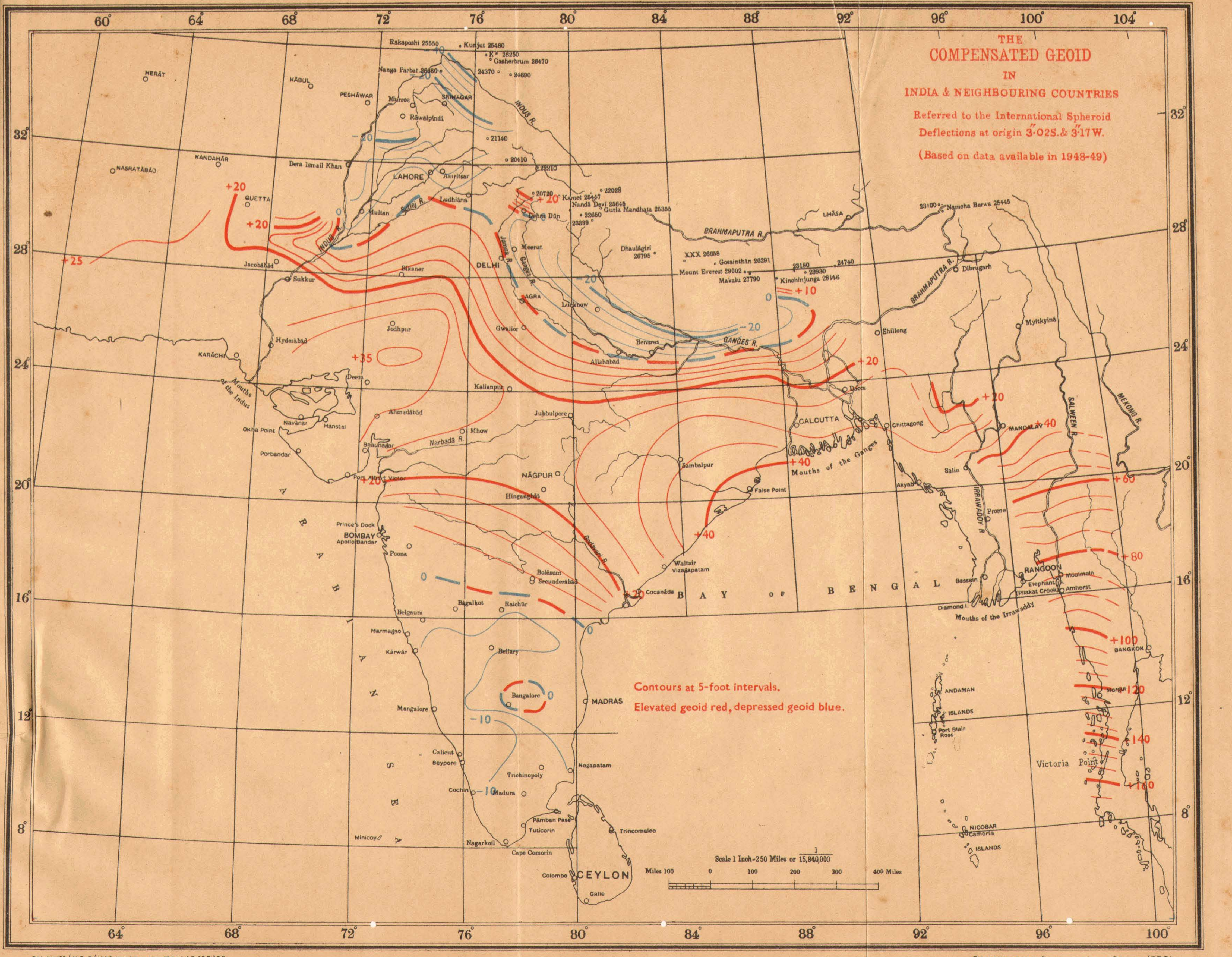
Chart XXIV



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and the entire closing error of the circuit was applied to the weaker sections to obtain geoidal heights at the various stations of observation. The addition of two new strong sections has necessitated the redistribution of the closing errors of the circuits, each station now receiving a correction proportional to its distance from the starting station.

A comparison of Chart XIII of the last year's Report with Chart XXIII of this Report shows that whereas the general picture of the Geoid in South India has remained the same as before in some areas the contours have shifted upwards by about 5 feet.

In Central India the general picture is altered considerably. The closed +35-foot contour connecting Jubbulpore and Nāgpur and the small +40-foot local contour within this have disappeard, as also the +30-foot closed contour between Ahmedabād and Mhow.

As regards the Compensated Geoid (Chart XXIV) the contours in the South have altered materially in shape but not in magnitude. In the centre the +30-foot closed contour to the north of Nāgpur has disappeared. A prominent feature of the new chart is a wide saddle in the centre of India formed by contours of +20 and +25 feet.

The closed—40-foot oval to the north of Benaras has been replaced by a—25-foot contour.

Towards the north also, the contours above +20 feet have all shifted in the north-east direction. The displacement of zero contour is by about −8 feet.

55. **Future Geoidal Programme.**—The geoidal circuit Mangalore–Bangalore–Poona–Mangalore had a large closure error of +56 feet (vide Geodetic Report 1935, Chart VIII). In 1935–36, the two weak E. to W. sections of this circuit were re-observed and Geodetic Report 1936, page 27 says that as a consequence the error was reduced to +25 feet. This was, however, a mistake, and the correct figure is −3 feet which is very satisfactory.

It is now on the programme to carry out a line of latitude observations north of Bombay although the existing closure of the circuit of which this line forms a part appears to be good. This line is, however, weak and the small closure error can only be attributed to chance.

With the completion of the last two seasons' work, the main geoidal framework in India is pretty well braced up except in the north where observation of a section Jalpaiguri–Pota–Meerut along the North-East Longitudinal Series is indicated. As mentioned in Chapter IV of Technical Report 1947, Part III, some further stations in Burma along Mandalay to Dibrugarh or on Manipur Road are desirable to form a closed circuit and carry out geoid into unexplored regions. These would, however, be impossibly difficult at the moment not only on account of the existing conditions in Burma but also due to the fact that determination of geodetic positions would be a serious problem. Primary stations are few and old topographical points are notoriously bad and of doubtful accuracy, being burdened with errors of as much as 200 yards.

TABLE 1.—*Laplace stations observed during 1948–49.*

Stations		Astronomical Co-ordinates			Geodetic Co-ordinates			P.V. deflections from azimuth from 1934–42 observations	P.V. deflections from longitude from 1948–49 observations	Correction to geodetic azimuth accepted previously	New correction to geodetic azimuth
		Latitude	Longitude	Azimuth	Latitude	Longitude	Azimuth				
		° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″	″	″	″
Tinsmal	H.S.	**24 07 12·92**	**78 59 43·98**	**285 50 42·8**	24 07 12·97	78 59 45·27	285 50 40·6		+1·7		+1·4
				..							
Rangir	S.	**24 00 17·53**	**79 25 56·40**	**106 01 23·9**	24 00 20·37	79 25 59·25	106 01 22·4	−29·6	+0·3	+1·8	+1·4
		24 00 19·28	..	106 01 11·1	..	..	..				
Amua	H.S.	**23 59 56·54**	**80 29 13·95**	**260 04 21·6**	23 59 56·24	80 29 17·26	260 04 20·4	+5·4	−0·1	−1·4	+1·3
		23 59 57·02	..	260 04 21·4	..	..	..				
Lakanpura	H.S.	**24 02 52·06**	**80 47 22·50**	**80 11 44·9**	24 02 49·92	80 47 24·49	80 11 43·1	..	+1·1	..	+1·3
Karara	H.S.	**24 04 41·32**	**81 15 41·70**	**269 18 23·6**	24 04 42·01	81 15 47·29	269 18 36·7	−13·9	−2·2	−1·8	−7·1
		24 04 42·20	..	269 18 28·7	..	..	..				

NOTE :—The new 1948–49 astronomical values are given in heavy type, old values are given in ordinary type.

DEFLECTION STATIONS

TABLE 2

Serial No.	Sheet No.	Observed at	Height in feet	International Spheroid Deflections		Calculated Deflections Hayford System		Calculated Deflections Uncompensated Topography	
				Meridian	P.V.	Meridian	P.V.	Meridian	P.V.
				″	″	″	″	″	″
1164	53 F	Dehra Dūn Base, W. End S.	1782		−11·5				
1165	45 G	Sumerpur A.I.D. Pillar	878	− 2·0	+ 2·0				
1166	45 G	Pāwa A.I.D. Pillar	734	+ 3·2	+ 1·8				
1167	66 D	Vandalūr h.s.	563	+ 3·6	− 1·2				
1168	57 P	Chingleput R.S.	121	+ 2·4	− 2·9				
1169	P	Near NE. cabin, Tezhuppadu R.S.	115	+ 3·3	− 1·1				
1170	P	Mailām h.s.	338	+ 5·3	− 0·3				
1171	58 M	Mallipat H.S.	302	+ 3·3	− 1·0				
1172	M	Tiruvendipuram Lat. station	115	+ 3·7	− 1·2				
1173	M	Chidambaram s.	173	− 1·8	− 2·6				
1174	M	Vaithīsvarankoil	..	− 5·8	+ 1·2				
1175	N	Tiruvālūr s.	145	− 9·0	− 0·2				
1176	N	Patukota Trestle S.	88	+ 1·6	− 1·0				
1177	N	Pallathivayal Trestle S.	150	+ 4·8	− 5·6				
1178	66 C	St. Thomas's Mount Trestle S.	250	+ 4·8	− 3·3				
1179	72 N	Tamarang h.s.	3298	−38·3	−15·1				
1180	65 N	Rāmchandarpur h.s.	541	− 5·1					
1181	N	Pindi H.S.	766	− 2·8					
1182	65 N	Pālkonda ..	176	− 9·1					
1183	65 M	Lowagudi h.s.	1865	− 2·0					
1184	M	Nowerah	1947	− 4·1					
1185	M	Kondaul	2400	− 0·2					
1186	64 P	Undunduli	2327	+ 2·9					
1187	P	Girdah	2118	+ 7·1					

COLUMN 4: Except at G.T. and other triangulation stations all heights are approximate and correct to within 10 to 20 feet.

DEFLECTIONS 1947–49

EVEREST'S SPHEROID						
Latitude	Longitude	Azimuth	Name of station observed for Azimuth	Deflections		Serial No.
				Meridian	P.V.	
° ′ ″	° ′ ″	° ′ ″	″	″	″	
A	A 77 51 24·3	293 40 05·1	Dehra Dūn			
G 30 19 43·25	G 77 51 41·38	293 40 07·4	Base, E. End S.		−12·0	1165
A 25 09 33·61	A 73 05 01·32			− 5·0	+ 4·5	1164
G 25 09 38·58	G 73 04 59·53					
A 25 25 03·26	A 73 04 40·51			0·0	+ 4·2	1166
G 25 25 03·24	G 73 04 39·07					
A 12 53 52·25	A 80 05 42·56			+ 5·0	− 3·0	1167
G 12 53 47·28	G 80 05 48·76					
A 12 41 36·37	A 79 58 48·55			+ 3·8	− 4·6	1168
G 12 41 32·6	G 79 58 56·4					
A 12 22 20·44	A 79 47 18·90			+ 4·9	− 2·7	1169
G 12 22 15·5	G 79 47 24·8					
A 12 07 54·49	A 79 36 58·20					
G 12 07 47·60	G 79 37 03·16			+ 6·9	− 1·8	1170
A 11 58 05·29	A 79 22 28·20			+ 5·0	− 2·4	1171
G 11 58 00·26	G 79 22 33·84					
A 11 44 43·07	A 79 42 39·80			+ 5·4	− 2·8	1172
G 11 44 37·64	G 79 42 45·80					
A 11 24 00·43	A 79 41 32·60			+ 0·1	− 4·2	1173
G 11 24 00·32	G 79 41 40·03					
A 11 11 41·47	A 79 42 45·45			− 3·8	− 0·5	1174
G 11 11 45·3	G 79 42 49·1					
A 10 46 22·72	A 79 37 55·73			− 6·8	− 1·7	1175
G 10 46 29·50	G 79 38 00·63					
A 10 26 20·94	A 79 17 58·34			+ 3·8	− 2·3	1176
G 10 26 17·09	G 79 18 03·85					
A 10 09 18·43	A 79 00 51·15			+ 7·2	− 6·7	1177
G 10 09 11·23	G 79 01 01·10					
A 13 00 20·93	A 80 11 32·85			+ 6·1	− 5·2	1178
G 13 00 14·79	G 80 11 41·38					
A 26 52 56·80	A 87 11 24·15			− 42*	−21*	1179
G 26 53 39*	G 87 11 51*					
A 18 07 10·27				− 5·4		1180
G 18 07 15·71	G 83 42 16·41					
A 18 19 35·04				− 3·2		1181
G 18 19 38·28	G 83 45 12·18					
A 18 36 29·76				− 9·6		1182
G 18 36 39·35	G 83 46 06·35					
A 19 05 31·74				− 2·7		1183
G 19 05 34·40	G 83 44 31·95					
A 19 17 44·43				− 4·9		1184
G 19 17 49·32	G 83 44 56·95					
A 19 40 46·06				− 1·2		1185
G 19 40 47·26	G 83 40 17·68					
A 20 06 02·02				+ 1·9		1186
G 20 06 00·16	G 83 43 12·36					
A 20 21 17·64				+ 6·0		1187
G 20 21 11·60	G 83 43 05·56					

NOTE :—*Minus* sign denotes N. or E. deflection of the plumb-line.
* Doubtful.

(Continued)

TABLE 2

Serial No.	Sheet No.	Observed at	Height in feet	International Spheroid Deflections		Calculated Deflections Hayford System		Calculated Deflections Uncompensated Topography	
				Meridian	P.V.	Meridian	P.V.	Meridian	P.V.
				″	″	″	″	″	″
1188	64 P	Gantapara	1231	+ 4·6					
1189	P	Majurguda	655	+ 0·7					
1190	O	Singhijuba H.S.	1136	− 1·0					
1191	O	Attabira	554	+ 1·3					
1192	O	Aliapara	995	− 2·1					
1193	O	Ustali H.S.	1694	+ 3·7					
1194	N	Mouwa H.S.	1935	− 1·2					
1195	N	Burha No. 1	1834	− 1·4					
1196	N	Kosanga H.S.	3194	− 2·8					
1197	M	Bhanwar	3374	− 3·9					
1198	M	Pataghársa	3800	+ 7·0					
1199	M	Chiwari	1997	+12·4					
1200	M	Sewādhi H.S.	1954	+10·1					
1201	54 L	Tinsmāl H.S.	2141	+ 2·7	+ 2·9				
257	P	Rangīr S.	1186	− 0·2	+ 1·7				
378	64 A	Amūa H.S.	2120	+ 2·9	+ 1·9				
1202	63 D	Lakanpura H.S.	1780	+ 4·8	+ 3·3				
357	63 H	Karāra H.S.	1966	+ 2·0	+ 0·3				
1203	H	Marwās H.S.	1776	+ 0·8	+ 1·3				
1204	83 E	Jorum h.s.	6422	− 9	+21				
1205	E	Pad Puttu h.s.	7103	−17	+10				
1206	83 I	North Lakhimpur s.	328	−28	+10				

COLUMN 4: Except at G.T. and other triangulation stations all heights are approximate and correct to within 10 to 20 feet.

DEFLECTIONS 1948–49

EVEREST'S SPHEROID						
Latitude	Longitude	Azimuth	Name of station observed for Azimuth	Deflections		Serial No.
				Meridian	P.V.	
° ′ ″	° ′ ″	° ″		″	″	
A 20 32 54·44						1188
G 20 32 51·02	G 83 42 07·50			+ 3·4		
A 20 52 32·97				− 0·6		1189
G 20 52 33·59	G 83 46 10·11					
A 21 03 30·23				− 2·4		1190
G 21 03 32·61	G 83 45 09·57					
A 21 21 37·01				− 0·2		1191
G 21 21 37·23	G 83 47 14·29					
A 21 44 35·14				− 3·8		1192
G 21 44 38·97	G 83 46 28·96					
A 21 59 33·70				+ 1·9		1193
G 21 59 31·85	G 83 42 48·70					
A 22 14 43·40				− 3·1		1194
G 22 14 46·51	G 83 42 25·27					
A 22 28 49·23				− 3·4		1195
G 22 28 52·64	G 83 46 08·44					
A 22 46 51·18				− 5·0		1196
G 22 46 56·22	G 83 46 57·46					
A 23 05 10·95				− 6·1		1197
G 23 05 17·02	G 83 45 59·15					
A 23 24 43·89				+ 4·7		1198
G 23 24 39·23	G 83 46 26·69					
A 23 36 20·39				+10·0		1199
G 23 36 10·36	G 83 47 51·32					
A 23 58 31·67				+ 7·5		1200
G 23 58 24·17	G 83 45 12·84					
A 24 07 12·92	A 78 59 43·98	A 285 50 43·4	Rangīr S.	− 0·1	+ 1·7	1201
G 24 07 12·97	G 78 59 45·27	G 285 50 42·6				
A 24 00 17·53	A 79 25 56·40	A 106 01 23·2	Tinsmal H.S.	− 2·8	+ 0·3	257
G 24 00 20·37	G 79 25 59·25	G 106 01 23·1				
A 23 59 56·54	A 80 29 13·95	A 260 04 21·7	Lakhanpura H.S.	+ 0·3	− 0·1	378
G 23 59 56·24	G 80 29 17·26	G 260 04 21·8				
A 24 02 52·06	A 80 47 22·50	A 80 11 44·8	Amūa H.S.	+ 2·1	+ 1·1	1202
G 24 02 49·92	G 80 47 24·49	G 80 11 44·3				
A 24 04 41·32	A 81 15 41·70	A 269 18 28·6	Marwār H.S.	− 0·7	− 2·2	357
G 24 04 42·01	G 81 15 47·29	G 269 18 29·0				
A 24 04 57·40	A 81 46 30·45	A 89 31 09·9	Karāra H.S.	− 1·9	− 1·5	1203
G 24 04 59·33	G 81 46 35·28	G 89 31 10·6				
A 27 30 48	A 93 48 32	A 131 06 28	Point 25	−12	+11	1204
G 27 31 00	G 93 48 23	G 131 06 23				
A 27 33 41	A 93 42 50	A 272 01 55	Duta h.s.	−20	0	1205
G 27 34 01	G 93 42 53	G 272 01 55				
A 27 13 50	A 94 06 31	A 137 24 33	North Lakhimpur Satellite s.	−31	0	1206
G 27 14 21	G 94 06 34	G 137 24 33				

NOTE :—*Minus* sign denotes N. or E. deflection of the plumb-line.

CHAPTER V

TIDES

BY B. L. GULATEE, M.A. (CANTAB.)

56. **Tidal Observations.**—(*a*) *By port authorities.*—Registrations with automatic gauges were continued by the port authorities at Aden, Karāchi*, Bombay (Apollo Bandar), Vizagapatam and Calcutta (Kidderpore). The Kent's Pneumatic gauge at Dublat (Saugor) which had to be shut down in September 1943 due to erosion of the foreshore had been re-installed by the Calcutta Port Commissioners in March 1944 and has since been working continuously. Three more self-registering gauges of the Kent's Pneumatic type had been established by the Calcutta Port Commissioners during the recent years along the Hooghly, one being at Gangra (established in April 1940 but destroyed by cyclone in October 1942 and re-installed in December 1942), another at Balari (established in August 1940) and the third at Diamond Harbour (established in January 1947), and have all been in operation during the period under report. Daylight observations of high and low waters on tide-poles were also continued at Bhāvnagar and Chittagong*.

The tidal observatory at Bombay was inspected by the Surveyor of the Port Trust in May 1948 and again by the Chief Engineer in December 1948. The Observatory at Calcutta was inspected by the River Surveyor of the Calcutta Port Commissioners in May 1948. No inspection reports were received from any of the other observatories.

Only a few breaks occurred in the above tidal registrations. The following table gives details of these breaks :—

Port	Dates of breaks	REMARKS
Aden ..	9–10 Sept. 1948	Due to some unknown obstruction.
	6–8 Feb. 1949	Do.
Karāchi* ..	23–24 Jan. 1948	Causes not known.
	8–12 Feb. 1948	
	22–24 Feb. 1948	
Bombay ..	28 Nov.–2 Dec. 1947	Due to accidental interference by dock workers.
	8–10 Mar. 1948	Due to breakage of lead substitutes.
	10–14 May 1948	Due to inspection of gauge.
	27–30 Nov. 1948	Due to breakage of the silver chain.
Vizagapatam ..	23–24 May 1948	Due to pen not touching the diagram paper.
	22–31 Dec. 1948	Due to overhauling of the gauge.

* Observatory Reports from Karāchi and Chittagong have not been received since March 1948 but it is presumed observations have been in progress.

But for these minor interruptions, all the gauges were working satisfactorily.

(*b*) *By touring tidal detachment of the Survey of India.*—A programme of 29 days' systematic observations was carried out by a touring tidal detachment, newly formed in the Department, at a number of ports along the west coast of India during the field seasons 1947–48 and 1948–49. The need for starting such a regular short-period observation programme had long been felt for two main reasons : (i) our predictions for Standard Ports rest, in most cases, on observations taken about 60 years ago, and no recent "actuals" have been available to check whether the predictions continue to conform reasonably to the "actuals" or whether local changes in the sea bed and configuration of the land in the harbour have since taken place affecting the tidal occurrences to any appreciable extent ; and (ii) in the case of most Secondary Ports, only inferred harmonic constants are given in the Admiralty Tide-Tables, and no modern systematic observations have been available to provide reliable harmonic data for the use of the mariners. Observations were carried out at Cochin, Beypore and Bassein (Bombay Presidency) during the season 1947–48 and at Port Okha, Mandvi (Kutch), Porbandar and Bhāvnagar during 1948–49. The observations at each port consisted of tide-pole readings at intervals of every half-hour during both day and night, and also at times of high and low waters, for 29 consecutive days.

At the Standard Ports Cochin, Beypore, Okha, Porbandar and Bhāvnagar the tide-pole was installed practically at (or very close to) the old tide gauge sites, so that the results of the present observations and analysis could be compared with the previous values. At the Secondary Ports Bassein and Mandvi, sites were chosen at the best available spots, in consultation with the respective port authorities.

The zero of the tide-pole was, in every case, tied on to atleast two permanent bench-marks on the shore by levelling, and a watch was kept on this zero throughout the observations, by frequent levelling on to the reference bench-marks, to ensure that the tide-pole remained firm and undisturbed. The half-hourly tide readings on the staff were recorded to 0·1 ft., while the readings near about the times of high or low water (which were recorded at every 5 minutes commencing from about a quarter of an hour before the expected high or low water to about a quarter of an hour after) were estimated and recorded to 0·01 ft.

The detachment comprised an officer in charge (Mr. M. K. Bose), four Record-keepers (or tide-watchers) and five class IV servants. For the season 1947–48, the party left Dehra Dūn for the field on 3rd December 1947 and after carrying out the observations at Cochin, Beypore and Bassein, returned to the Headquarters on 5th April 1948. For the season 1948–49, the party left the Headquarters on 13th October 1948 and returned on 24th March 1949 after completing observations at four ports. The health of the detachment during both the seasons remained satisfactory.

57. **Harmonic Analysis.**—The observations of 1947–48 were harmonically analysed by the Admiralty Method of Harmonic Analysis, during the recess. The results of this analysis, together with the comparative values of the constants which have hitherto been (and still are) in use for our annual predictions, are given in Table 1(*a*).

It will be seen from the table that the old constants* for Cochin and Beypore have not undergone any appreciable change during the last 60 years or so. Predictions obtained from the old and new constants are practically the same and show no significant variance. The conclusion is that our present predictions for these ports have not appreciably deteriorated in quality and that the old harmonic constants need no change at present.

The predictions in the case of Cochin, however, have been found to differ from the observed "actuals" consistently by about 4 inches in the same direction. Table 1(*b*) shows a statement of these differences. Whether this consistent difference is due to any coastal subsidence, or to a sinkage of the reference bench-marks or to some other cause is under investigation. Certain data of recent tidal observations carried out by the Cochin port authorities for their harbour development schemes have been obtained in this connection and are being studied.

For Bassein, the "inferred" harmonic constants given in the Admiralty Tide-Tables Part II can now be replaced by the more reliable constants now derived, so that reasonably accurate predictions may hereafter be possible for purposes of navigation.

The field observations of 1948–49 have not yet been analysed. Their results will be published in the next Technical Report.

58. **Tide-Tables.**—The annual "Tide Tables of the Indian Ocean" and the three separate pamphlets for Bombay, the Hooghly River and the Rangoon River for the year 1949 were prepared and published during July–Sept. 1948.

Advance predictions for the years 1949 and 1950 for a number of ports were sent, in December 1947 and December 1948 respectively, to the Hydrographic Departments in England and the United States and to the Royal Indian Navy, as usual.

At the request of the R.I.N., special tidal predictions for Rozi (in the gulf of Kutch) for the year 1948 were prepared and supplied, both in tables and charts form, on payment.

The total realization from the sale of tide-tables (exclusive of agents' commission) and from the supply of paid-for data during the period under report was Rs. 10,658-15-0.

59. **Mean Sea-Level.**—At the request of the International Hydrographic Bureau, values of the monthly and annual Mean Sea-

* Only the nine major constants that are obtainable by the Admiralty Method of Harmonic Analysis, have here been considered.

Level at Aden, Karāchi, Bhāvnagar, Bombay, Vizagapatam, Saugor, Kidderpore, Chittagong, Akyab and Rangoon for the years 1939–47 were computed and supplied. The values, however, could only be derived from the high and low water observations, and not rigorously from hourly heights. The annual M.S.L. values are given in Table 2.

Monthly and annual values of the Mean Sea-Level at Dublat (& Saugor) for the years 1881–86 and 1937–43 were also supplied to the Port Commissioners, Calcutta, at their request.

60. **Corrections to Predictions.**—Empirical corrections based on the "actuals" of recent years have, as before, been applied to the predictions for Karāchi, Navlakhi, Bhāvnagar, Bombay (A. B.), Vizagapatam, Chāndbāli, Dublat, Kidderpore and Rangoon for the years 1949–51. In the case of Navlakhi, Chāndbāli, Chittagong and Rangoon, the same corrections as were applied for the 1948 predictions (see Technical Report 1947, Part III) were used, while for the remaining ports the values were revised. These revised values are given in Tables 3 to 8.

61. **Accuracy of Predictions.**—Table 9 gives the greatest errors in the predicted heights of low water during 1947 and 1948 at the ports at which "actuals" were observed.

The detailed results of the comparison between the predicted and observed tides during 1939–48 have been worked out but are not reproduced here for want of space. It may be mentioned that the average (P—A) discrepancies have remained insignificant, except in the case of Chittagong, Karāchi and Bhāvnagar where some large discrepancies appear to have crept in during the war. Observed data at Chittagong and Karāchi have not been available since March 1948. The probable cause of the large discrepancies at these ports has been given in the previous Technical Report. The effect of the bar at Bhavnagar has been dealt with in the form of empirical corrections to predictions and the (P—A) discrepancies are now reasonably small.

62. **Prediction Methods.**—With the object of improving the present method of our riverain predictions, a start has been made with trying out Liverpool Institute's method of Harmonic Shallow Water Corrections in the case of Rangoon. The method consists in analysing harmonically the (P—A) discrepancies for certain dominant shallow water constituents which have been ignored in the primary predictions as obtained from the tide machine. These constituents are set on the machine to obtain correction curves for high water times, high water heights, low water times and low water heights, to supplement the primary predictions. Rangoon has been taken as a start, and the (P—A) discrepancies for the year 1941 are now in the process of analysis and study.

Similarly special methods involving consideration of shallow water components will have to be applied to Saugor, Diamond Harbour, Kidderpore and other riverain ports of the Indian Ocean.

63. **Additional Tidal Observations.**—The need for the installation of a number of additional permanent tidal observatories along the Indian coast, to supplement the ones at Bombay and Kidderpore and to help various tidal and other geophysical investigations, is being strongly felt, and it is proposed to open a few such observatories before long. A resolution that was adopted in this connection by the International Union of Geodesy and Geophysics at their eighth meeting held at Oslo in August 1948 reads: "The International Union of Geodesy and Geophysics considers that to provide data for a satisfactory study of M.S.L. and its variations on the Indo–Burma–Malaya–Siamese waters and also for detailed studies of many other geophysical problems such as the secular subsidence or elevation of land, the present number of active tide-gauge stations on the Indo–Burma coast is far from adequate, and strongly recommends to the Governments concerned the establishment of a number of additional permanent tide-gauge observatories on their coasts as soon as practicable." This resolution was put up by the author, and action is in hand to procure the necessary tide-gauges for the purpose. The present Tidal Section of this Department will suitably be expanded to cope with the increased work when these observatories are installed.

It is considered that in addition to the existing tide-gauge stations, the establishment of permanent stations at the following ports along the Indian coast would be very useful :—

1.	Kandla/Navlakhi	Gulf of Kutch
2.	Navanar/Mandvi	Gulf of Kutch
3.	Veraval/Porbandar	Kathiawar Coast
4.	Karwār	West Coast
5.	Ratnāgiri	West Coast
6.	Beypore	West Coast
7.	Cochin	West Coast
8.	Minicoy	Minicoy Island
9.	Tuticorin	East Coast
10.	Negapatam	East Coast
11.	Dhamra Point/Shortt Island	East Coast
12.	Port Blair	Andaman Islands

In view of the Kandla project and the complex nature of the creeks through which tides find their way to the port, a proposal is under way to install three or four tide-gauges at different points along the Kandla coast as early as possible.

64. **Miscellaneous.**—The tide predicting machine remained out of order for about 2 months during the last year due to certain gear wheels having got worn out and wanting replacements. New gear wheels of the required specifications were made and substituted for the worn-out ones without much difficulty. The machine has since been in working order, though it is felt that sooner or later certain other worn-out parts also (e.g., the crank-pins, the slots of the T-pieces) will have to be replaced to maintain the necessary accuracy.

TABLE 1(*a*).—*Harmonic Tidal Constants derived from 29 days' observations, by the Admiralty Method of Harmonic Analysis*

Serial No.	Place & position (with description of tide-pole site)	Period of observation and central day	Level of zero of tide-pole below chart datum (or zero of predictions)	Level of zero of tide-pole below B.M. of reference	Harmonic Constants	Constituent M_2	S_2	N_2	K_2	K_1	O_1	P_1	M_4	MS_4	A_0	Description of B.M. of reference
			ft.	ft.		*Indian Standard Time (05h 30m fast on G.M.T.)*										
1	COCHIN* Lat: 9° 58′ N.; Long: 76° 15′ E. (At the old tide-gauge site)	29 days	0·83	9·31	Old 1886-92 H ft.	0·73	0·26	0·16	0·08	0·59	0·31	0·17	0·03	0·02	1·91	G.T.S. A □ B.M. embedded in the centre of the verandah of the Port Office.
					$g°$	339	042	307	036	058	059	056	089	159		
		30-12-47			New 1947 H ft.	0·68	0·29	0·16	0·08	0·56	0·29	0·18	0·03	0·03	†2·19	
					$g°$	329	040	297	040	053	065	053	064	141		
2	BEYPORE* Lat: 11° 10′ N.; Long: 75° 48′ E. (About 50 yds. south of the old tide-gauge site)	29 days	−0·29	17·00	Old 1878-84 H ft.	0·94	0·33	0·20	0·08	0·71	0·34	0·20	0·02	0·01	2·88	G.T.S. A □ B.M. embedded about 100 ft. E. of front door of Custom House.
					$g°$	336	030	308	023	058	058	059	054	095		
		4-2-48			New 1948 H ft.	0·92	0·38	0·21	0·10	0·83	0·36	0·27	0·04	0·04	†2·84	
					$g°$	331	027	300	027	055	058	055	030	112		
3	BASSEIN Lat: 19° 18′ N; Long: 72° 48′ E. At the junction of stream and Bassein creek about 50 yds. E. of the Custom House.	29 days	−0·90§	17·47	'Inferred' Adm. T.T. Pt. II H ft.	4·1	1·6			1·5	0·7				7·5	Flag stone second step leading to the main entrance of the Custom House.
					$g°$	357	036			058	054					
		16-3-48			New 1948 H ft.	3·92	1·44	0·86	0·39	1·56	0·69	0·52	0·28	0·20	§7·5	
					$g°$	006	044	348	044	060	050	060	303	352		

* Standard Ports. † Corrected for seasonal corrections. § Provisional value.

TABLE 1(*b*).—*Comparison of the predicted and actual heights at Cochin during Dec. 1947–Jan. 1948.*

Date	High Water			Low Water		
	Predicted Height	Actual Height	Error Pred.—Act.	Predicted Height	Actual Height	Error Pred.—Act.
	ft.	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*
16 Dec. 1947	3·7	4·0	— 0·3	2·1	2·1	0·0
	2·6	2·8	— 0·2	0·7	1·1	— 0·4
17 ,,	3·6	3·8	— 0·2	2·0	2·3	— 0·3
	2·5	3·0	— 0·5	0·9	1·4	— 0·5
18 ,,	3·6	3·9	— 0·3	2·0	2·4	— 0·4
	2·4	2·9	— 0·5	1·1	1·6	— 0·5
19 ,,	3·5	3·8	— 0·3	1·9	2·3	— 0·4
	2·4	2·9	— 0·5	1·3	1·8	— 0·5
20 ,,	3·4	3·7	— 0·3	1·7	2·2	— 0·5
	2·4	2·8	— 0·4	1·7	2·0	— 0·3
21 ,,	3·3	3·7	— 0·4	1·6	2·0	— 0·4
	2·4	2·8	— 0·4	2·0	2·4	— 0·4
22 ,,	3·1	3·6	— 0·5	..	..	..
	2·6	3·1	— 0·5	1·4	1·8	— 0·4
23 ,,	3·0	3·6	— 0·6	2·3	2·7	— 0·4
	2·9	3·3	— 0·4	1·1	1·6	— 0·5
24 ,,	2·9	3·3	— 0·4	2·6	3·0	— 0·4
	3·2	3·4	— 0·2	0·9	1·3	— 0·4
25 ,,	2·9	3·2	— 0·3	2·6	2·9	— 0·3
	..	..	..	0·6	1·0	— 0·4
26 ,,	3·5	3·8	— 0·3	2·6	3·0	— 0·4
	2·9	3·2	— 0·3	0·4	0·8	— 0·4
27 ,,	3·7	3·9	— 0·2	2·5	2·7	— 0·2
	2·9	3·3	— 0·4	0·2	0·6	— 0·4
28 ,,	3·9	4·0	— 0·1	2·4	2·6	— 0·2
	2·9	3·3	— 0·4	0·1	0·6	— 0·5
29 ,,	4·0	4·3	— 0·3	2·3	2·6	— 0·3
	2·9	3·3	— 0·4	0·1	0·5	— 0·4
30 ,,	4·0	4·2	— 0·2	2·1	2·2	— 0·1
	2·9	3·3	— 0·4	0·3	0·7	— 0·4
31 ,,	3·9	4·2	— 0·3	1·9	2·2	— 0·3
	2·8	3·3	— 0·5	0·6	1·0	— 0·4
1 Jan. 1948	3·8	4·0	— 0·2	1·7	2·0	— 0·3
	2·8	3·2	— 0·4	1·0	1·3	— 0·3
2 ,,	3·7	4·0	— 0·3	1·4	1·7	— 0·3
	2·7	3·1	— 0·4	1·4	1·7	— 0·3
3 ,,	3·6	4·0	— 0·4	1·2	1·6	— 0·4
	2·7	3·1	— 0·4	1·8	2·1	— 0·3
4 ,,	3·4	3·9	— 0·5	1·1	1·5	— 0·4
	2·8	3·2	— 0·4	2·3	2·6	— 0·3
5 ,,	3·3	3·7	— 0·4	..	..	..
	2·9	3·3	— 0·4	0·9	1·4	— 0·5
6 ,,	3·1	3·5	— 0·4	2·6	2·8	— 0·2
	3·2	3·6	— 0·4	0·9	1·3	— 0·4
7 ,,	2·9	3·3	— 0·4	2·7	3·0	— 0·3
	3·4	3·7	— 0·3	0·8	1·1	— 0·3
8 ,,	2·8	3·1	— 0·3	2·6	2·8	— 0·2
	..	..	..	0·8	1·0	— 0·2
9 ,,	3·6	3·6	0·0	2·5	2·5	0·0
	2·6	2·8	— 0·2	0·7	1·0	— 0·3
10 ,,	3·7	3·8	— 0·1	2·4	2·5	— 0·1
	2·6	2·9	— 0·3	0·7	1·0	— 0·3
11 ,,	3·7	3·9	— 0·2	2·3	2·4	— 0·1
	2·5	2·9	— 0·4	0·8	0·9	— 0·1
12 ,,	3·8	3·8	0·0	2·2	2·2	0·0
	2·5	2·8	— 0·3	0·8	1·0	— 0·2
13 ,,	3·7	3·8	— 0·1	2·1	2·3	— 0·2
	2·5	3·1	— 0·6	0·8	1·0	— 0·2
Sum ..	..	..	—18·8	..	..	—17·6
Mean ..	..	..	— 0·3	..	..	— 0·3

TABLE 2.—*Values of Annual Mean Sea-Level derived from High and Low waters*

Year	Aden	Karāchi	Bhāvnagar*	Bombay (Apollo Bandar)	Vizagapatam	Dublat	Kidderpore	Chittagong*	Akyab*	Rangoon
1939	..	5·4	19·7	8·4	2·6	9·7	10·6	6·8	4·4	10·4
1940	4·5	5·4	19·7	8·5	2·5	9·6	10·1	6·8	4·3	10·2
1941	4·5	5·5	19·8	8·4	2·5	9·6	10·4	7·0	4·5	10·2
1942	4·5	5·4	19·6	8·4	2·6	9·6	10·7	..	..	..
1943	4·4	5·2	19·8	8·5	2·7	..	10·7	..	..	..
1944	..	5·3	20·5	8·5	2·4	..	10·1	6·4	..	..
1945	..	5·3	20·3	8·4	2·6	..	10·3	6·7	..	..
1946	4·4	5·4	20·2	8·5	..	..	10·4	6·8	..	..
1947	4·5	..	20·5	8·4	2·6	..	..	7·0	..	10·2*

* Only daylight observations of high and low waters have been available.

TABLE 3.—*Corrections applied to the predicted times and heights at Karāchi for 1949–51.*

Year	1949*				1950–51†			
	H.W.		L.W.		H.W.		L.W.	
Month	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*
January ..	− 3	+0·3	− 4	0·0	Nil	+0·3	Nil	Nil
February ..	− 1	+0·4	− 2	0·0				
March ..	0	+0·4	− 6	0·0				
April ..	0	+0·2	− 3	−0·1				
May ..	+ 2	+0·2	− 1	−0·1				
June ..	+ 2	+0·1	− 1	−0·2				
July ..	+ 2	+0·2	0	0·0				
August ..	0	+0·5	− 2	+0·2				
September ..	0	+0·4	− 2	+0·2				
October ..	+ 1	+0·3	0	0·0				
November ..	+ 4	+0·4	+ 2	0·0				
December ..	+ 2	+0·3	+ 1	0·0				

* Corrections based on (P — A) differences during 1941–45.
† ,, ,, ,, ,, ,, ,, 1942–45 and 1947.

TABLE 4.—*Corrections applied to the predicted times and heights at Bhāvnagar for 1949–51.*

Year	1949*				1950†				1951‡			
	H.W.		L.W.		H.W.		L.W.		H.W.		L.W.	
Month	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*
Jan.	−15	+0·4	+43	See Table 4 (a)	−15	+0·5	+45	See Table 4 (a)	−10	+0·5	+50	See Table 4 (a)
Feb.	−16	+0·4	+48		−15	+0·5	+50		−10	+0·4	+50	
March	−17	+0·5	+47		−15	+0·6	+45		−10	+0·6	+50	
April	−12	+0·4	+45		−10	+0·7	+45		−10	+0·6	+50	
May	−12	+0·2	+46		−10	+0·4	+50		−10	+0·3	+50	
June	−13	+0·4	+44		−10	+0·4	+50		−10	+0·4	+50	
July	−13	+0·6	+50		−10	+0·6	+50		−10	+0·4	+50	
Aug.	−12	+1·1	+52		−10	+1·1	+50		−10	+1·0	+50	
Sept.	−12	+0·9	+49		−10	+0·9	+50		−10	+0·9	+50	
Oct.	−11	+0·6	+46		−10	+0·8	+50		−10	+0·7	+50	
Nov.	−11	+0·5	+40		−10	+0·6	+40		−10	+0·4	+40	
Dec.	−12	+0·3	+40		−10	+0·4	+40		−10	+0·2	+40	

* Corrections based on (P − A) differences during 1942–46.
† ,, ,, ,, ,, ,, ,, 1943–47.
‡ ,, ,, ,, ,, ,, ,, 1944–48.

TABLE 4(*a*).—*Corrections applied to the predicted heights of L.W. at Bhāvnagar for 1949–51.*

Predicted height in feet	1949	1950	1951	Predicted height in feet	1949	1950	1951
	Corrections in feet				Corrections in feet		
0·0	6·0	6·1	5·8	5·0	2·5	2·3	2·1
0·1	5·9	6·0	5·8	5·1	2·5	2·2	2·1
0·2	5·8	5·9	5·7	5·2	2·4	2·2	2·0
0·3	5·8	5·9	5·6	5·3	2·3	2·1	1·9
0·4	5·7	5·8	5·5	5·4	2·3	2·1	1·9
0·5	5·7	5·7	5·5	5·5	2·2	2·0	1·8
0·6	5·6	5·6	5·4	5·6	2·2	1·9	1·8
0·7	5·5	5·5	5·3	5·7	2·1	1·9	1·7
0·8	5·4	5·5	5·3	5·8	2·1	1·8	1·7
0·9	5·4	5·4	5·2	5·9	2·0	1·8	1·6
1·0	5·3	5·3	5·1	6·0	2·0	1·7	1·6
1·1	5·3	5·3	5·0	6·1	1·9	1·7	1·5
1·2	5·2	5·2	5·0	6·2	1·8	1·6	1·5
1·3	5·1	5·1	4·9	6·3	1·8	1·6	1·4
1·4	5·0	5·0	4·8	6·4	1·7	1·6	1·4
1·5	5·0	5·0	4·7	6·5	1·6	1·5	1·3
1·6	4·9	4·9	4·6	6·6	1·6	1·5	1·3
1·7	4·8	4·8	4·5	6·7	1·5	1·4	1·3
1·8	4·8	4·7	4·5	6·8	1·5	1·4	1·2
1·9	4·7	4·7	4·4	6·9	1·4	1·3	1·2
2·0	4·6	4·6	4·3	7·0	1·4	1·3	1·1
2·1	4·6	4·5	4·2	7·1	1·3	1·2	1·1
2·2	4·5	4·4	4·2	7·2	1·2	1·2	1·0
2·3	4·4	4·3	4·1	7·3	1·2	1·2	1·0
2·4	4·4	4·2	4·0	7·4	1·1	1·1	1·0
2·5	4·3	4·1	3·9	7·5	1·1	1·1	1·0
2·6	4·2	4·1	3·8	7·6	1·0	1·0	0·9
2·7	4·2	4·0	3·8	7·7	1·0	1·0	0·9
2·8	4·2	3·9	3·7	7·8	1·0	0·9	0·9
2·9	4·1	3·8	3·6	7·9	0·9	0·9	0·8
3·0	4·0	3·8	3·5	8·0	0·8	0·9	0·8
3·1	3·9	3·7	3·5	8·1	0·7	0·8	0·8
3·2	3·8	3·6	3·4	8·2	0·7	0·8	0·7
3·3	3·8	3·5	3·3	8·3	0·7	0·8	0·7
3·4	3·7	3·4	3·2	8·4	0·6	0·7	0·7
3·5	3·7	3·3	3·2	8·5	0·6	0·7	0·7
3·6	3·6	3·2	3·1	8·6	0·5	0·6	0·6
3·7	3·5	3·1	3·0	8·7	0·5	0·6	0·6
3·8	3·5	3·1	2·9	8·8	0·4	0·6	0·6
3·9	3·4	3·0	2·9	8·9	0·4	0·5	0·6
4·0	3·3	3·0	2·8	9·0	0·3	0·5	0·5
4·1	3·2	2·9	2·7	9·1	0·3	0·5	0·5
4·2	3·2	2·8	2·7	9·2	0·3	0·5	0·5
4·3	3·1	2·7	2·6	9·3	0·3	0·5	0·5
4·4	3·0	2·7	2·5	9·4	0·2	0·5	0·5
4·5	2·9	2·6	2·4	9·5	0·2	0·4	0·4
4·6	2·8	2·6	2·4	9·6	0·2	0·4	0·4
4·7	2·7	2·5	2·3	9·7	0·2	0·4	0·4
4·8	2·7	2·4	2·2	9·8	0·2	0·4	0·4
4·9	2·6	2·3	2·2	9·9	0·2	0·4	0·4
5·0	2·5	2·3	2·1	10·0	0·1	0·3	0·4

(Continued)

TABLE 4(*a*).—*Corrections applied to the predicted heights of L.W. at Bhāvnagar for 1949–51.*

Predicted height in feet	1949	1950	1951	Predicted height in feet	1949	1950	1951
	Corrections in feet				Corrections in feet		
10·1	0·1	0·3	0·4	11·6	0·0	0·3	0·2
10·2	0·1	0·3	0·4	11·7	0·0	0·3	0·2
10·3	0·1	0·3	0·3	11·8	0·0	0·3	0·2
10·4	0·1	0·3	0·3	11·9	0·0	0·3	0·2
10·5	0·1	0·3	0·3	12·0 to 13·0	−0·1	0·3	0·2
10·6	0·1	0·3	0·3				
10·7	0·1	0·3	0·3				
10·8	0·1	0·3	0·3				
10·9	0·1	0·3	0·3	14·0 to 15·0	0·0	0·3	0·2
11·0	0·1	0·3	0·3				
11·1	0·1	0·3	0·3				
11·2	0·1	0·3	0·3				
11·3	0·0	0·3	0·3				
11·4	0·0	0·3	0·2				
11·5	0·0	0·3	0·2				

The corrections in each case have been derived from a mean graph prepared from 5 separate curves, each representing (P—A) differences corresponding to predicted heights during the latest 5 years. These corrections are consequent on the formation of a bar in the creek.

TABLE 5.—*Corrections applied to the predicted times and heights at Bombay (Apollo Bandar) for 1949–51.*

Year and Month	H.W. Time *min.*	H.W. Height *ft.*	L.W. Time *min.*	L.W. Height *ft.*
1949–1950*				
January to December ..	+ 4	+0·2	+ 4	+0·2
1951†				
January to December ..	0	+0·2	0	+0·2

* Corrections based on (P—A) differences during 1939–43.
† ,, ,, ,, ,, ,, ,, 1943–47.

TABLE 6.—*Corrections applied to the predicted times and heights at Vizagapatam for 1949–51.*

<table>
<tr><th>Year</th><th colspan="4">1949*</th><th colspan="4">1950†</th><th colspan="4">1951‡</th></tr>
<tr><th></th><th colspan="2">H.W.</th><th colspan="2">L.W.</th><th colspan="2">H.W.</th><th colspan="2">L.W.</th><th colspan="2">H.W.</th><th colspan="2">L.W.</th></tr>
<tr><th>Month</th><th>Time
min.</th><th>Height
ft.</th><th>Time
min.</th><th>Height
ft.</th><th>Time
min.</th><th>Height
ft.</th><th>Time
min.</th><th>Height
ft.</th><th>Time
min.</th><th>Height
ft.</th><th>Time
min.</th><th>Height
ft.</th></tr>
<tr><td>Jan.</td><td rowspan="12">−19</td><td rowspan="12">+0·1</td><td rowspan="12">−19</td><td rowspan="12">−0·1</td><td rowspan="12">−19</td><td>+0·2</td><td rowspan="12">−19</td><td>0·0</td><td rowspan="12">−19</td><td>+0·2</td><td rowspan="12">−19</td><td>+0·1</td></tr>
<tr><td>Feb.</td><td>+0·4</td><td>+0·2</td><td>+0·4</td><td>+0·2</td></tr>
<tr><td>March</td><td>+0·3</td><td>+0·2</td><td>+0·3</td><td>+0·2</td></tr>
<tr><td>April</td><td>+0·2</td><td>0·0</td><td>+0·2</td><td>0·0</td></tr>
<tr><td>May</td><td>0·0</td><td>−0·2</td><td>0·0</td><td>−0·2</td></tr>
<tr><td>June</td><td>0·0</td><td>−0·1</td><td>0·0</td><td>−0·2</td></tr>
<tr><td>July</td><td>0·0</td><td>−0·2</td><td>0·0</td><td>−0·2</td></tr>
<tr><td>Aug.</td><td>−0·2</td><td>−0·3</td><td>+0·1</td><td>−0·3</td></tr>
<tr><td>Sept.</td><td>0·0</td><td>−0·1</td><td>0·0</td><td>−0·2</td></tr>
<tr><td>Oct.</td><td>+0·1</td><td>0·0</td><td>+0·2</td><td>−0·1</td></tr>
<tr><td>Nov.</td><td>0·0</td><td>−0·2</td><td>0·0</td><td>−0·1</td></tr>
<tr><td>Dec.</td><td>0·0</td><td>0·0</td><td>0·0</td><td>0·0</td></tr>
</table>

* Corrections based on (P – A) differences during 1942–46.
† " " " " " " 1943–47.
‡ " " " " " " 1944–48.

TABLE 7.—*Corrections applied to the predicted times and heights at Dublat for 1949–51.*

Year and Month	H.W.		L.W.	
	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*
1949–50				
January to December ..	+ 4	+0·1	+ 4	+0·1
1951				
January to December ..	+ 4	0·0	+ 4	0·0

The corrections have been based on (P—A) differences obtained during 1938–42.

TABLE 8.—*Corrections applied to the predicted times and heights at Kidderpore for 1949–51.*

Year	1949*				1950†				1951‡			
	H.W.		L.W.		H.W.		L.W.		H.W.		L.W.	
Month	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*	Time *min.*	Height *ft.*
Jan.	+ 3	+0·3	+ 8	0·0	+ 3	+0·3	+ 8	0·0	+ 6	+0·3	+ 8	−0·1
Feb.	+ 5	+0·2	+ 8	0·0	+ 5	+0·3	+ 9	−0·1	+ 6	+0·4	+10	−0·1
March	+ 4	+0·4	+ 7	0·0	+ 3	+0·4	+ 6	0·0	+ 6	+0·4	+ 6	−0·2
April	+ 3	+0·4	+ 8	0·0	+ 4	+0·3	+ 9	−0·2	+ 3	+0·4	+ 6	−0·2
May	+ 1	+0·5	+ 4	+0·2	0	+0·6	+ 3	0·0	0	+0·7	0	0·0
June	− 1	+0·3	+ 2	−0·2	+ 1	0·0	+ 3	−0·4	+ 2	0·0	+ 2	−0·4
July	+ 4	−0·4	+ 4	−0·8	+ 5	−0·4	+ 1	−0·7	+ 8	−0·5	+ 2	−0·9
Aug.	+10	−0·1	+10	−0·9	+ 9	−0·2	+ 8	−1·1	+10	−0·3	+ 6	−1·2
Sept.	+ 7	+0·1	+ 5	−0·8	+ 7	0·0	+ 5	−1·0	+ 6	+0·1	+ 5	−1·1
Oct.	+ 3	+0·6	+ 4	−0·4	+ 3	+0·5	+ 1	−0·6	+ 3	+0·6	+ 2	−0·6
Nov.	+ 3	+0·4	+ 4	−0·4	+ 6	+0·4	+ 4	−0·5	+ 6	+0·5	+ 4	−0·4
Dec.	+ 3	+0·6	+ 6	0·0	+ 5	+0·6	+ 6	0·0	+ 6	+0·6	+ 6	0·0

* Corrections based on (P−A) differences during 1941–45.
† " " " " " " 1943–47.
‡ " " " " " " 1944–48.

TABLE 9.—*Greatest differences between the predicted and actual heights of Low Water during 1947–48.*

Port	Predicted *minus* actual	Date	REMARKS
Aden ..	*feet* – 1·9 – 1·2	2 May 1947 2 October 1948	
Karāchi ..	– 0·9 + 0·9 – 0·5 + 0·5	15 Jan., 21 Nov. 1947. 2 May 1947. 22 & 28 Jan. 1948. 2 Jan. & 7 Feb. 1948	Actuals not received after 1st March 1948.
Bhāvnagar ..	– 3·6 – 2·4	14 Oct. 1947. 4 Oct. 1948.	A bar has formed in the channel which obstructs the flow of water to the tide-pole, thereby affecting all tides below 9 ft. The mean range of the ordinary spring tides at this port is 31·5 ft.
Bombay (Apollo Bandar)	– 2·2 – 1·3	16 April 1947. 20 Nov. 1948.	
Vizagapatam ..	– 1·9 – 0·9	26 Oct. 1947. 12 Aug. 1948.	
Calcutta (Kidderpore)	+ 2·0 – 2·0 – 2·1	22 June & 1 Aug. 1947. 24 & 25 Oct. 1947. 14 Aug. 1948.	Riverain Port. Actuals from 5 Feb. to 2 May 1947 not available due to dock strike.
Chittagong ..	– 4·4 – 0·5	7 Aug. 1947. 28 Jan. 1948.	Riverain Port. Actuals not received after 1 March 1948.
Rangoon (Monkey Point)	– 4·2 – 1·9 + 1·9	23 Oct. 1947 4 April 1948. 24 June 22 & 23 July 1948.	Riverain Port. Tidal registrations are at Monkey Point about 1½ miles down the river.

CHAPTER VI

OBSERVATORIES

BY B. L. GULATEE, M.A. (CANTAB.)

65. **General.**—The principal work of the observatories consisted of :—

(i) Comparison and maintenance of standards of length;
(ii) Seismograph and meteorological observations;
(iii) Maintenance and adjustment of delicate scientific instruments stored in the Geodetic Branch;
(iv) Test, calibration and repair of various Survey Instruments;
(v) Instructions to officers in astronomical observations;
and (vi) Preparation of the annual Survey of India Star Almanac.

The Magnetic Observatory remained out of commission and no programme of field observations at Repeat Stations was carried out. Some special observations for horizontal and vertical force of earth's magnetism were made in the Kolar Gold Field and some other useful material was collected. These are discussed in paras 79 to 82.

66. **Comparison of Primary standard of the Survey of India with European standards.**—The Survey of India possesses the following modern metric standards of one metre length :—

1-metre Nickel.
1-metre Fused Silica.
1-metre Nickel Steel and 1-metre Invar.

Of these, 1-metre Nickel bar which was made by Societè Genevoise d' Instruments de Physique in 1911 is intended to be the fundamental standard and the others as auxiliaries for check and working purposes.

In view of the fact that all material bars, no matter how carefully handled undergo gradual secular variations, it is essential that the working bars should be intercompared frequently and that the standard should be compared against European standards after some years.

The Nickel metre was made by S.I.P. Geneva in 1911 and was standardized at the National Physical Laboratory, Teddington in 1914. Silica metre was constructed and calibrated at N.P.L. in 1925. Both these bars were sent back to N.P.L. in 1930 for re-standardization and it was found that between 1914 and 1930, Nickel metre had shortened by 0·0044 mm. ($= 4/10^6$) and Silica had increased by 0·0005 mm. ($= 1/2 \times 10^6$).

These bars were intercompared in the Indian Comparator in 1934 and 1937 and they seemed to have preserved their relative difference in length. In July 1947, the Nickel metre bar was taken to the National Physical Laboratory for restandardization. The certificate of length obtained is as follows :—

$$L_t = L_0 (1 + 0 \cdot 000{,}012,\ 396\ t + 0 \cdot 000{,}000{,}00836\ t^2),$$
$$L_{20°C} = 1 \text{ m} + 0 \cdot 2659 \text{ mm}.$$

where L_0 is the length at zero degree centigrade and L_t at $t°$ centigrade.

As mentioned this bar had been previously standardized in 1931 and it has been found to have decreased in length by 0·0004 mm. ($= 1/0 \cdot 4 \times 10^6$) during the period 1931 to 1947, which is very satisfactory.

67. **Meteorological and Seismological Observations.**—The usual meteorological observations, which are taken at 8 hours and 17 hours daily, have been continued throughout the year. Values of recorded temperature and pressure were supplied to the local Civil and Military Hospital, the Anti-Malaria Hospital and other Government agencies. Monthly meteorological data were sent to the Director Regional Meteorological Centre, New Delhi.

The Omori Seismograph was in operation throughout the year and worked satisfactorily.

A list of the earthquakes recorded at Dehra Dūn have been published in the Geodetic Reports printed before World War II. These tables have now been omitted from the new series of Technical Reports started after the war as they are being included in the Seismological Bulletin issued by the India Meteorological Department along with similar data for other observatories in India.

68. **The Riefler Clock.**—The Riefler electric clock has on the whole functioned satisfactorily throughout the year. The Shortt clock has had frequent stoppages. The Caustic Soda Cells, used to run the Shortt clock, are not giving the requisite steady current and hence the stoppages. Action is in hand to renew the plates which have already been indented for.

69. **Wireless sets.**—One of the two portable wireless sets R.P. 11 which had gone out of order was set right and has been issued to the Astronomical Detachment for field work during season 1948–49. These Marconi sets have now become too antiquated and do not give a satisfactory reception of the time signals on the ultra longwave. Some attempts have been made to receive short wave rhythmic signals with Hallicrafter SX28. Only GIA signals from Leafield on a frequency of 19,640 Mc/S have been successfully received. It appears that none of the 18:00 hours (G.M.T.) signals give a useful signal strength in India. Further tests are in progress.

The rating of the clocks has been done by hearing the B.B.C. time pips on an ordinary wireless receiver by Phillips.

70. Test, Calibration and Repair of Instruments.—During the period under report, 634 instruments of various kinds were tested and calibrated in the Observatory Section. The main calibration has been of 20-metre Invar tapes for field units which were compared against bays 1–6 of the 24-metre comparator. The other instruments calibrated were theodolites, levels, barometers, invar levelling staves for precision work and chronometers.

Some new Tavistock theodolites received from Messrs. Cooke Troughton & Simms were found on testing to have developed a serious defect by the wearing out of the adhesive property of the chemical used by the makers to stick the graduated glass circle to the lower horizontal plate of the theodolite. This resulted in the circle becoming eccentric and the instruments had to be sent to the makers for repairs.

Four hundred and thirty instruments of a replacement value of Rs. 2,80,000 were repaired during the year. The instruments for repairs included 31 glass arc theodolites, 60 vernier theodolites, 7 chronometers, 35 levels, 44 levelling staves, 10 Aneroid barometers, 20 calculating machines, 115 magnetic compasses, 102 drawing instruments and 27 clinometers.

Two invar H.S.B. Tapes were constructed and calibrated for the East-West Bengal Boundary Commission.

71. Calibration of Tapes for Topographical Works.—In the past, four steel tapes of 66-foot length were used with the H.S.B. equipment for the measurement of topographical bases. These tapes used to be standardized on the flat in a mural base, on which foot-marks have been put by a bevelled bar graduated in terms of 10-foot bar I_s. This bar is now obsolete and has not been compared against European standards for over 40 years. Six tapes were measured on the flat on the mural base and were also standardized on the 24-metre comparator in catenary and then reduced to flat. There was a large systematic difference between the results of the two measurements of as much as 0·014 feet. It has accordingly been decided to utilize 20 metres tapes instead 66 feet ones and to calibrate them in the 24-metre comparator. This has the additional advantage that the tapes get standardized while hanging in catenary under the same conditions as in the field.

72. The Telemeter of Precision.—The telemeter is a device which can be fitted to the Wild Universal Theodolite and enables distances between two traverse stations to be measured by a subtense method. It is contained in a cylindrical box and can be screwed on the object end of the theodolite for observing a special invar subtense staff placed at right angles to the line of sight of the theodolite. Two images of the staff are seen in the telemeter and are brought into coincidence. The readings on the scale at the coincidence of the images give the metres of the distance and the readings on the drum the centimetres. The vertical angles can also be read.

A trial telemeter traverse was run from Dalanwala Satellite S. to Dehra Dūn Base-Line East End S. and back—a total run of 18 miles, to test the precision attainable with the telemeter attachment. The traverse closed with an error of 1/7000 in scale and 0·6 feet in height. The outturn was about $1\frac{1}{4}$ miles a day. It is believed that with more practice both the outturn and the accuracy could be improved.

73. **Miscellaneous.**—Various field detachments of the Geodetic Branch were supplied with instruments, stores and equipment for field work during 1947–48 and 1948–49. A small stores section was organized for holding stores in current use.

All the delicate scientific instruments were maintained in good condition and adjustment.

Star Almanacs for 1948 and 1949 were compiled and published. Results of field observations with the astrolabe were computed.

Instruction was given to a number of young departmental officers in the use of astronomical instruments and observation.

74. **Seismological Observatory at Dehra Dūn.**—During 1947 the Government of India sanctioned the expansion of the Seismological organization in India under the Meteorological Department and as one item of this programme it had been proposed to equip some of the older seismological stations, of which Dehra Dūn is one, with more sensitive and modern types of instruments. Plans and detailed estimates of a new building in the compound of the Geodetic and Research Branch, Survey of India, Dehra Dūn to house the new instruments, which were to be supplied by the Meteorological Department were prepared by the local C.P.W.D. but this has not received financial sanction of the Government of India. The matter is being taken up with the Government by the Central Board of Geophysics.

75. **Dehra Dūn Magnetic Observatory.**—The underground Dehra Dūn Magnetic Observatory went out of commission in August 1943 due to heavy floods, which could not be controlled. It was reported in the last year's Technical Report (see page 118, para 73) that the sanction of the Government of India had been obtained to start a surface observatory at a new site about 15 miles away from Dehra Dūn close to the Dehra Dūn–Chakrata road. This statement was based on the fact that the report of the Geophysical Planning Committee which was accepted by the Government of India contained a recommendation to this effect. A site was selected and detailed plans and estimates of expenditure were prepared by the Executive Engineer, C.P.W.D., Dehra Dūn and submitted to the Government for financial sanction. For reasons of economy the Government of India have not given their approval to the project for the present, but the matter is being represented by the Central Board of Geophysics for reconsideration.

76. **Magnetic Charts.**—A complete set of isomagnetic charts for the epoch 1945·0 was received from the Hydrographer, U.S. Navy,

in February, 1948. The charts were drawn either on Mercator's projection on scale 1/36,000,000 or on Azimuthal equidistant projection on scale 1/11,000,000. They show the north and east components of horizontal force, vertical force and total force at intervals of 0·01 oersted, the declination at intervals of 1° and the dip at intervals of 2°. The isoporic lines are also given at intervals of 10 gamma for Horizontal and Vertical forces, 20 gamma for total force and 1′ for both declination and dip.

As mentioned in Technical Report 1947, Part III, Chapter VII, para 75, the Survey of India has prepared a magnetic variation chart for the epoch 1946·0 for India. A comparison between this and the corresponding chart by the U.S. Navy is shown in Chart XXV and is of interest. It would appear that the isogonic lines on the two charts are in general agreement except in northern India where differences of as much as 1° exist. These discrepancies may be due to the fact that the U.S. Navy charts are only generalized ones while our chart has been based on further observational data at repeat stations observed during the last war.

The trend of isoporic curves on the other hand is found to be remarkably different in the two charts. This is not entirely unexpected and affords yet another evidence of the fact that deduction of reliable secular variation is difficult and as such requires to be controlled by frequent observations at a sufficient number of Repeat Stations at regular intervals of about five years.

77. **Magnetic Equator.**—Chart XXVI shows the Magnetic Equator as derived from actual dip observations from the property that dip is zero there. It can also be drawn from theoretical considerations by assuming the Earth to be a centred dipole and eccentric dipole respectively. These latter determinations would naturally differ from the one derived from actual observed values of dip.

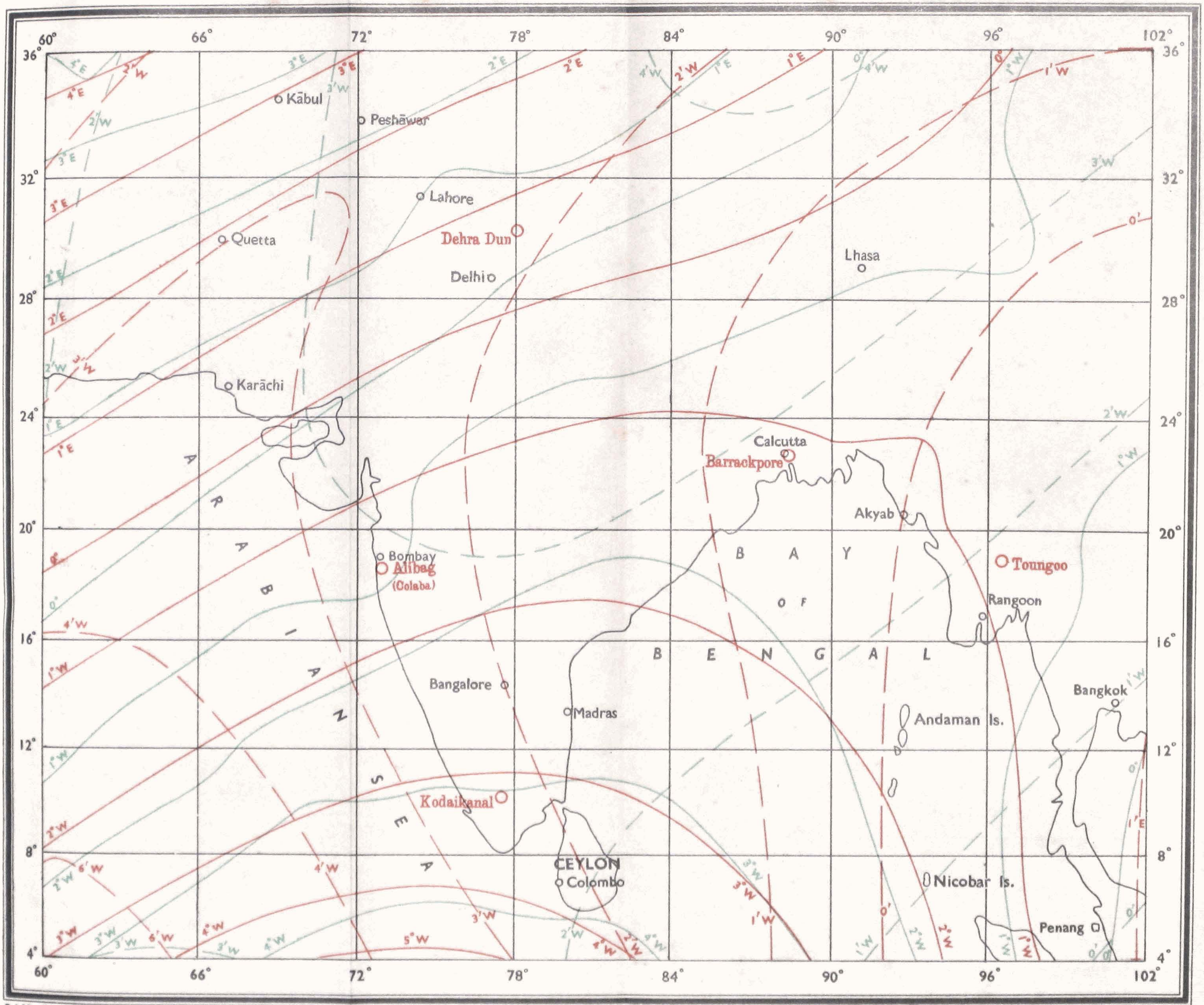
78. **Magnetic Variation in Subansiri Area (Assam).**—The Subansiri region in Assam falls in the nodal area in which the Isogonal lines are necessarily conjuctural. To obtain reliable values of magnetic declination for topographical sheets 83E and 83I, observations with the Wild Compass Theodolite were made at four stations in 1944-45 by Mr. M. W. Kalappa.

The results are as follows :—

Stations		Latitude			Longitude			Magnetic Variation	
		°	′	″	°	′	″	°	′
Jorum	h.s.	27	31	00	93	48	23	0	35·3 W.
Pad Pattu	h.s.	27	34	01	93	42	53	0	36·2 W.
Lonkho	h.s.	27	37	37	93	53	05	0	30·3 W.
North Lakhimpur Satellite	s.	27	14	26	94	06	29	0	40·0 W.

COMPARISION OF U. S. A. AND INDIAN VERSIONS OF ISOGONIC AND ISOPORIC CURVES IN INDIA

Chart XXV



R.S.No. 582 M/NCD'50(G.&T.C. 1"=300 Miles (approx)-375.

Scale 1 Inch=300 Miles (approx.)

Printed at the Survey of India Offices (P. Z. O.).

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Annual change ,, ,, ,, ,, ,, ,, ,, (Compiled at the Royal Obsy. Greenwich)

Magnetic Variation ,, ,, U. S. Navy Chart, ,, 1945·0 . . . .

Annual change ,, ,, ,, ,, ,, ,, ,, ...

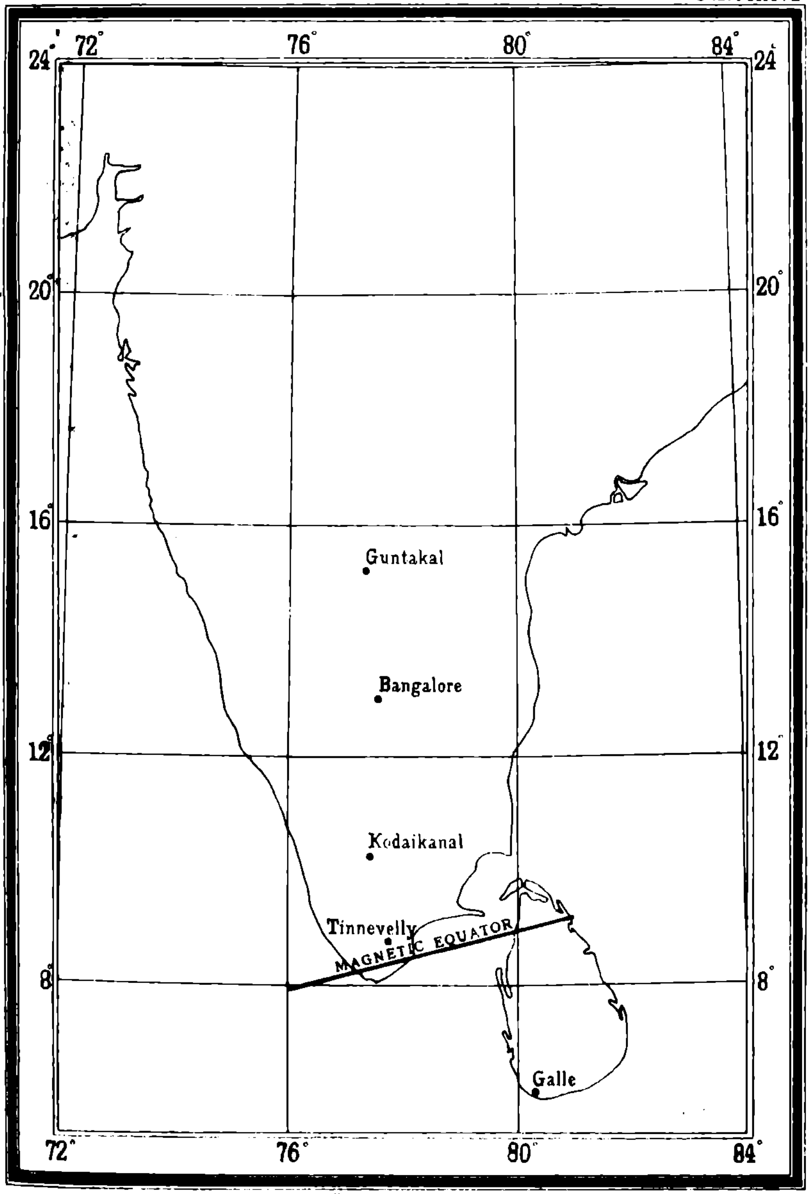
Magnetic Observatories . . . . Alibag (Colaba)

MAGNETIC EQUATOR
IN
INDIA

Scale 1 Inch = 250 Miles or $\frac{1}{15,840,000}$

Miles 100 0 100 200 300 Miles

Chart XXVI



R.S.No.584M/NCD'50 (G&T.C. 1" = 250 Miles)-375.

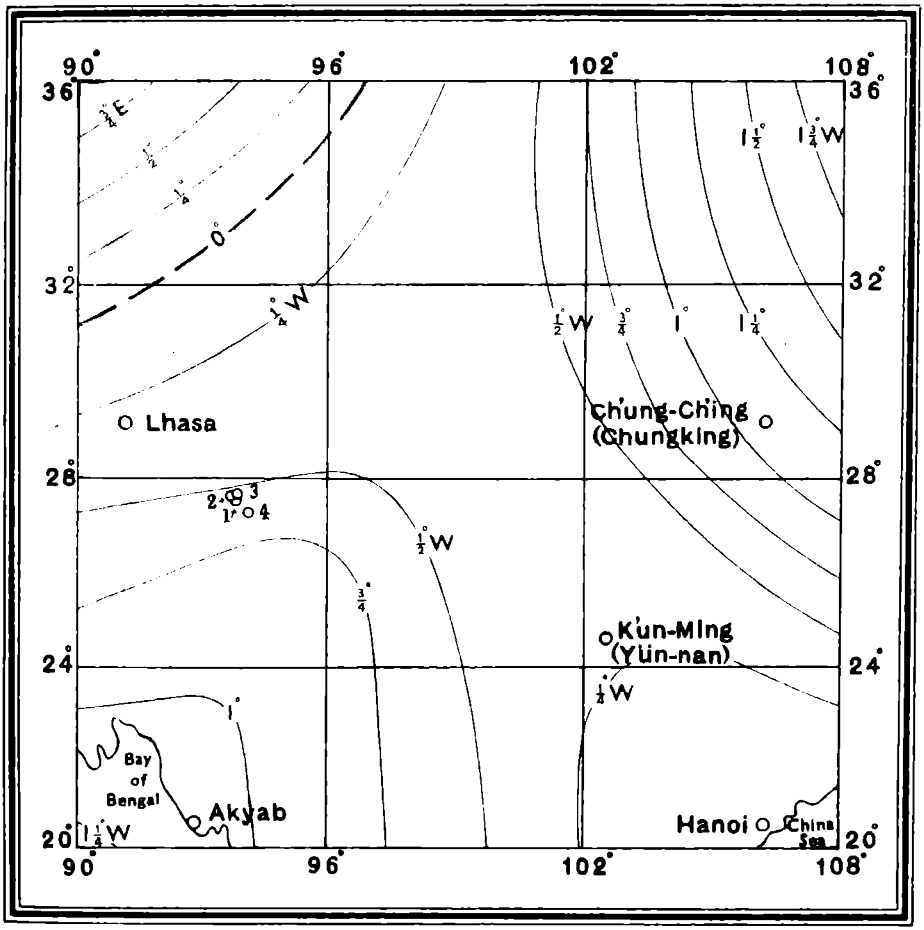
Printed at the Survey of India Offices (P. Z.O.)

Magnetic Variation

In

Subansiri Area (Assam)

Scale 1" = 300 Miles (approx) Chart XXVII



1 Jorum h.s.

2 Pad Pattu h.s.

3 Lonkho h.s.

4 North Lakhimpur Satellite s.

PRINTED AT THE SURVEY OF INDIA OFFICES (P.Z.O.).

Reg. No. 577M/N.C.D'50 (G. & T. C. 1" = 300 Miles approx)-375.

This data was not available at the time, the magnetic variation chart 1946 was drawn and has been plotted in Chart XXVII.

79. **Magnetic Observations in Kolar Gold Field**.—In view of modern theories on magnetism, the "Core Theory" and Blackett's "Bulk Theory", the determination of horizontal and vertical magnetic forces at various depths inside the earth has assumed special significance. On the hypothesis of earth's magnetic field being due to magnetism present in earth's core only, both H and V should increase with depth. Blackett's theory, however, assumes magnetism to be a universal property of matter in rotation and so according to it the outer layers of the earth will also contribute to the magnetic field of earth. It has been shown that on this theory, V will still increase with depth but H should decrease. A measurement of the magnetic field in a deep mine at different levels should thus provide a crucial test between the two theories.

The Kolar Gold Field provided a very convenient site for the purpose and with the kind co-operation of Messrs. John Taylor & Sons Committee, it was possible to carry out observations up to a depth of 8679 ft. at the Nundydroog mines. The final results are tabulated below :—

Date	Depth of station of observation	Vertical Force (Station value—Base value at surface)
	ft.	*gamma*
2-12-48	872	− 10
,,	1750	+ 13
,,	2768	− 1
,,	4199	+ 30
3-12-48	6875	+ 92
6-12-48	8679	+125
Date	**Depth of station of observation**	**Horizontal Force (Station value—Base value at surface)**
	ft.	*gamma*
7-12-48	872	− 38
3-12-48	6875	+281
6-12-48	8679	+249

The vertical force observations were taken with the Watts V.F. Variometers which are supposed to be temperature compensated. Two instruments were used—one at the base station for the diurnal variation and the other at different levels. The scale values of the two instruments were 19·4 and 25·5 γ respectively. Simultaneous observations were taken with both instruments before and after the close of the observations to check their relative index errors. The closure errors displayed by the field instrument in an interval of about 4 hours after correcting for diurnal variation are 21, 13 and 16 gammas respectively on the three days of observations. These can be regarded as quite satisfactory considering that the instrument had to go through a variation of temperature of as much as 40°F. The closure errors were duly distributed in the observed values.

No H.F. Variometers were available and consequently the horizontal force observations were carried out with two Kew Pattern Magnetometers (Nos. 5 and 10), one at the base and one for field work. These observations were very trying especially at deep levels (where temperatures were very high) as they take much more time than the V.F. observations. The values of moments of the magnets were determined by the usual vibration and deflection observations at the surface. Inside the mine, on account of uncomfortable conditions, only deflection observations were taken to save time. These give m/H, from which H was derived by utilizing the known value of m. The closure errors of the field instrument No. 5 on the three days were 37, 33 and 16 gammas respectively.

The working temperatures were as follows :—

Depth in feet	*Temperature*
0	74° F
872	84° F
1750	81° F
2768	90·5° F
4199	97° F
6875	96° F
8679	113° F

The Magnetometers not being temperature compensated, it was necessary to take account of the variation of the moment of the magnet with temperature. Magnetic moment m_t at $t°$ C. is related to its moment m_0 at 0° C. by $m_t = m_0 \ (1 - \alpha t - \beta t^2)$. The values of the temperature coefficients α, β for the two magnets were determined at Kew in about 1901 and are as follows :—

For magnet No. 5B $\left.\begin{array}{l}\alpha = 394 \cdot 5 \times 10^{-6} \\ \beta = 437 \cdot 5 \times 10^{-9}\end{array}\right\}$ per 1°C.

For magnet No. 10 $\left.\begin{array}{l}\alpha = 394 \times 10^{-6} \\ \beta = 475 \times 10^{-9}\end{array}\right\}$ per 1°C.

An error of 1×10^{-4} in $\alpha + 2\beta t$ (where t is the working temperature) produces an error of about 70 gammas in H and so it is necessary to have a precise knowledge of these temperature coefficients. It was considered that after this considerable lapse of time, the magnets might have changed their temperature coefficients and accordingly they were despatched to the Physical Laboratories of the Manchester University for recalibration. It was found that they had not altered at all, which speaks very highly for the quality of these magnets.

80. Interpretation.—The vertical field in the Kolar Gold Field area is about 0·075 gauss. This gives a predicted change of V between the surface and the station 8,679 feet deep of about 9 gammas which is about a fourteenth of the observed results. The Horizontal force also increases with depth.

The geology of this area comprises of auriferous quartz veins running parallel to one another in a north–south direction in a belt of hornblende schists. Regional metamorphism has converted igneous rocks of Dharwar age into many varieties of Hornblendic Schists, in which a little Ilmenite/Magnetite is present. Reef quartz is also by no means just pure quartz—it is magnetic and is very irregularly mineralised.

In selecting the stations of observations, the proximity of the ore was avoided and the instrument was put in cross cuts running in a direction perpendicular to the reef. To guard against the presence of local magnetic rocks and other material, the instrument was shifted a few feet in either direction and only those stations were finally selected where the reading did not change.

Samples of rocks were brought from the various levels and their susceptibilities were determined at Delhi University with the following results :—

1. Schist (Depth 1,750 ft.)	$K=16\times10^{-6}$	(Weakly paramagnetic)
2. Two samples of Schist (Depth 2,768 ft.)	$K=34\times10^{-6}$ $K=30\times10^{-6}$	(Strongly paramagnetic)
3. Schist (Depth 6,875 ft.)	$K=0{\cdot}4\times10^{-6}$	(Very weakly paramagnetic)
4. Champion Reef (Depth 8,679 ft.)	$K=196\times10^{-6}$	(Very strongly paramagnetic)
5. Dyke	$K=1347\times10^{-6}$	(Almost ferromagnetic.)

It was considered that the anomalous vertical gradient in V might be due to the high magnetic susceptibility of the schist and Prof. Blackett suggested magnetic survey over the surface to confirm it.

81. Surface Survey Observations.—This survey was done with two vertical force Watts Variometers Nos. 19134 and 19135 with scale values of 25·5 and 19·4 gammas respectively. The area covered was about 15 square miles covering the entire mining area of the Kolar Gold Fields and points were taken ¼ mile apart on a grid of about 3 miles by 5 miles.

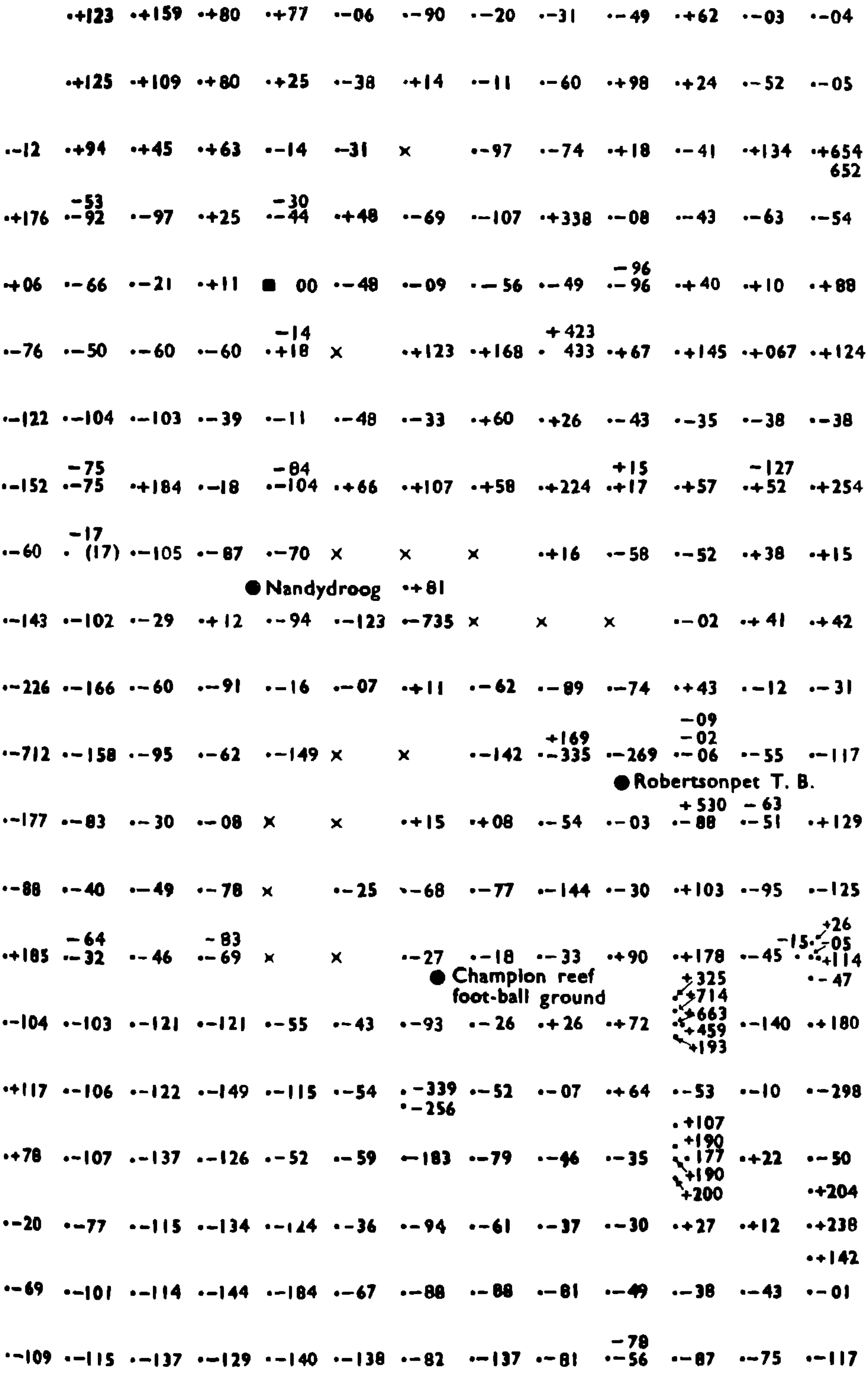
A detachment under Mr. S. Vaikuntanathan, M.A., with a computer and one *khalasi* left Dehra Dūn on the 2nd March and returned back to headquarters on the completion of the work on 27th March 1949.

About 250 stations were observed at, their location being established by pacing and the prismatic compass. Three base stations were made for the entire area for observations of diurnal variation—observations at these stations being taken every quarter of an hour. Simultaneous observations were made at the beginning and close of observations each day and the base stations were so chosen that continuity was ensured. All built up installations were avoided and safe minimal distances were kept from such objects as barbed wires, iron gates, rails and so on. Stations were also kept away from outcrops of igneous rocks and boulders.

82. **Results.**—Chart XXVIII shows the magnetic anomalies in gamma after applying the closure error and diurnal variation correction. At some of the stations, where there were sudden jumps in values, some more observations were taken round the place and these values are also recorded on the chart. It would appear from an examination of the chart that the magnetic fields is not at all smooth and there are large gradients. Although the various samples of schist that were collected displayed a considerable variation of magnetic susceptibility, the main disturbances must, however arise from the hornblendic rocks and granitic material. The unexpectedly large vertical gradient down to about 9,000 feet may thus be well due to the area being magnetically disturbed. The conclusion is that the values of V and H in Kolar Gold Field mines are not representative of the radiation with depth of the main field of the earth.

Chart XXVIII

MAGNETIC ANOMALIES (VERTICAL FORCE), KOLAR GOLD FIELD, 1947—48



Field station with Vertical Force anomaly in gammas in terms of Datum station shown thus:— • —167

× Sites not suitable for observations. ● Base stations. ■ Datum station.

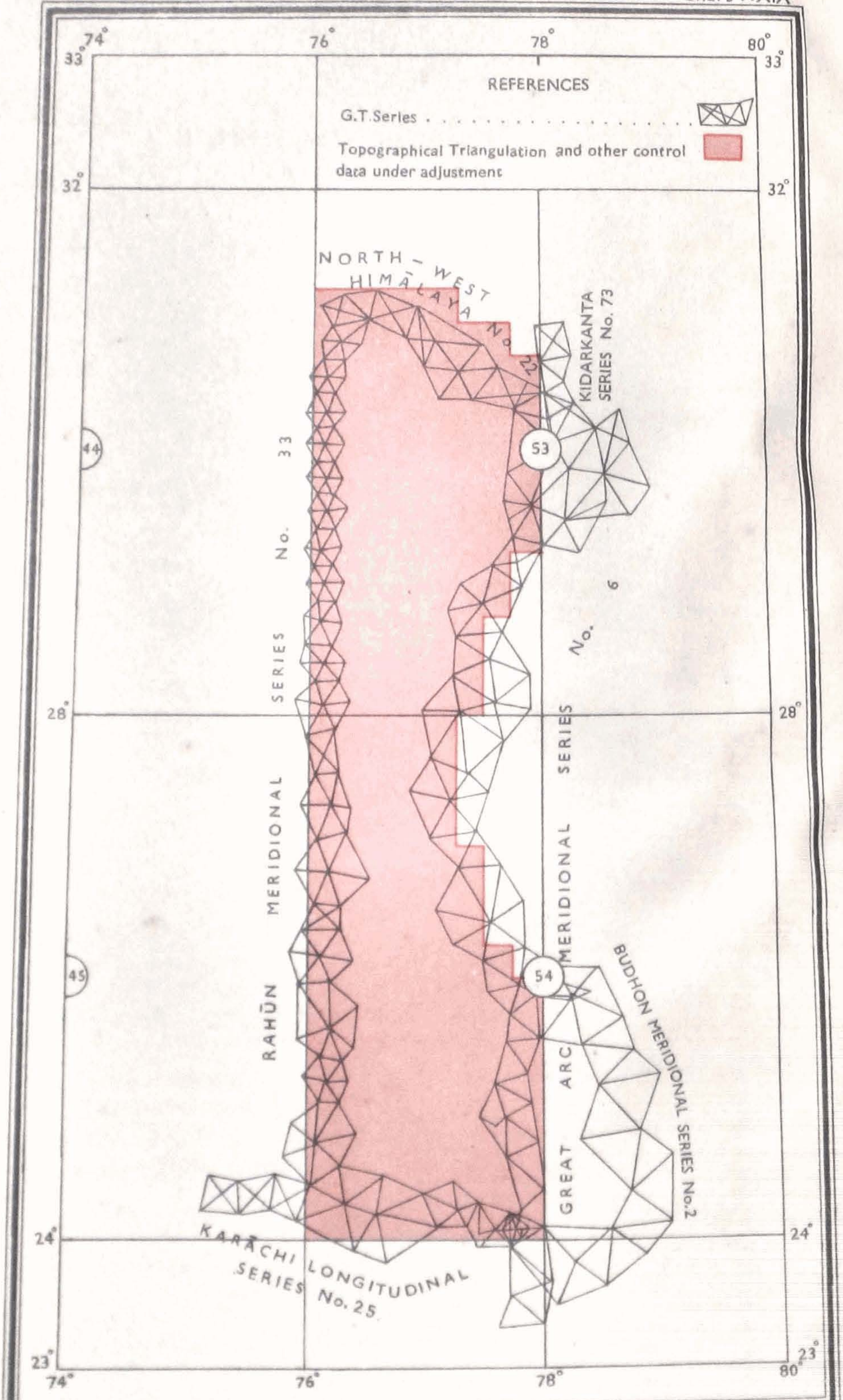
Scale 1·4″=1 Mile.

Furlongs 8 4 0 1 Miles

R.S.No.881 M/NCD'50(G.&T.C. 1·4″=1 Mile)—375. Printed at the Survey of India Offices (P.Z.O.)

Block of Topographical Triangulations under adjustment (Northern India)

Chart XXIX



Scale 1 Inch=96 Miles or 1:6,082,560

Miles 100 50 0 100 Miles

Reg. No. 596 M/N C D'50 (G. & T. C. 1"=96 Miles)-375.
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Chapter VII

COMPUTATIONS AND PUBLICATIONS

BY B. L. GULATEE, M.A. (CANTAB.)

83. General.—The main occupation of the Computing Office during the period under report has been the training of new computers, the supply of triangulation, traverse and levelling data to departmental and non-departmental units, the preparation of a second edition of certain levelling pamphlets, the reprint of some Auxiliary Tables and Professional forms and the maintenance of the progress charts of the various field detachments. Some progress has also been made with the readjustment of the triangulation by the Mesopotamia Expeditionary Force in Persia executed during World War I and the printing of data of Paiforce triangulation (see Technical Report 1947, Part III, paras 47 and 48). The M.E.F. triangulation is very weak and has mostly been superseded by Paiforce triangulation ; there are, however, areas in which the only data is that of this triangulation and it has consequently had to be retained and readjusted.

Much work could not, however, be done on the systematic adjustment of topographical triangulation all over India and its publication in pamphlets, due to shortage of suitably trained personnel.

84. Adjustment of Topographical Triangulation in India.—The bulk of the topographical triangulation carried out during the last half century to provide control for the 1-inch map of India is lying uncompiled, unadjusted and in an unpublished condition.

Most of the old computation volumes have no triangulation charts and the computations are faulty. It is estimated that the adjustment and publication of this huge mass of data comprising about 3½ lakhs of points in India alone (excluding Pakistan and Burma) will take 30 computers about 30 years to complete.

In spite of the dearth of personnel, a serious start has been made to adjust and compile good quality work with a view to publication in a series of complete data pamphlets, arranged by degree sheets. Charts XXIX and XXX show the blocks in which work is now in progress.

The first block covering parts of 1/M sheets 53 and 54 is bounded on the north by G.T. Series No. 22 (North-West Himālaya), on the south by G.T. Series No. 25 (Karāchi Longitudinal), on the west by G.T. Series No. 33 (Rahūn Meridional) and on the east by G.T. Series No. 6 (Great Arc Meridional between latitudes 24° and 30°

N.). Work in this block is concentrated on the production of a complete data pamphlet for sheet 54 A.

The second block covering parts of 1/M sheets 47 and 48 is bounded on the north by Series No. 7 (Bombay Longitudinal), on the west and south by Series No. 11 (South Konkan Coast), and on the east by Series No. 49 (Mangalore Meridional). The preparation of complete data pamphlet for sheet 47 F is well advanced in this area.

Some preliminary scrutiny of the records, compilation, and recomputation of some series has also been carried out in the Southern Circle in 1/M Sheets 48 and 58.

85. **Triangulation Data in Persia and Irāq.**—Technical Report 1947, Part III, paras 46 to 49 describe in detail the existing triangulation in Persia and Irāq. The adjustment of this triangulation has been completed and a start has now been made with the publication of the data in pamphlet form. The whole data will comprise of about 80 pamphlets out of which 16 have so far been published. The work is being continued and it is hoped that the job would be completed in about 2 to 3 years.

86. **Azimuthal Maps.**—On demand from the Director Military Survey, India, calculations were made for the preparation of three one-centred azimuthal maps of the World giving true bearings from Mhow, Poona and Calcutta respectively.

87. **Publications.**—The following publications were seen through the press :—

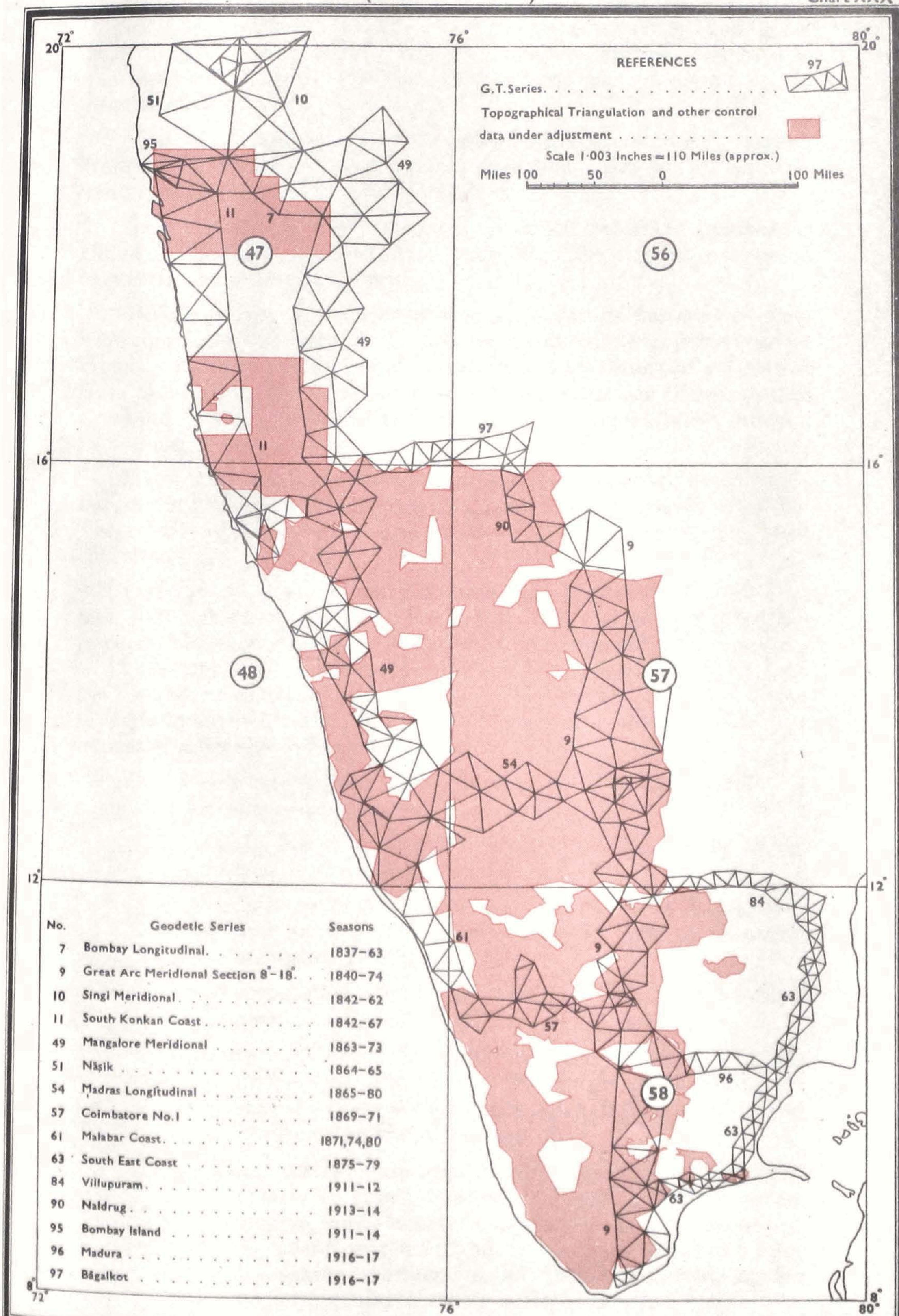
1. Report on the Geodetic Work of the Survey of India for the period 1939–48, presented at the Eighth Meeting of the International Union of Geodesy and Geophysics held at Oslo in August 1948.
2. Technical Report 1947, Part III, Geodetic Work.
3. Levelling pamphlets for 1/M sheets 78, 73 and 55.
4. Auxiliary Tables, reprinted.
   Part II. Mathematical Tables.
   Part III. Topographical Survey Tables.
5. Grid data triangulation pamphlets 56 E, F, G, H, I, J, K, N and O.

88. **Computation of Heights observed with Paulin Barometers.**—Four Paulin barometers were used in the Rānīganj and Nāgpur areas of gravimetric survey (see Chapter III, para 27) for determination of heights of gravimetric stations. These stations were also connected either by spirit-levelling or Tacheometric levelling in order to be able to judge the performance of these instruments under field conditions. The following routine was followed.

Two of the Paulin barometers (Nos. 1769 and 2782) were used for field observations and the other two (Nos. 2904 and 2927) for base observations, which were taken at intervals of 30 minutes.

Blocks of Topographical Triangulations under adjustment
(Southern India)

Chart XXX



R.S. No. 585M/NCD'50 (G&T.C. 1·003" = 110 Miles)–375.

Printed at the Survey of India Offices (P.Z.O.).

At the base both wet and dry bulb temperatures were read; the field observer recorded only dry bulb temperature and the time at the observing station, the observation being always closed at the base at close of work.

The field observations were often made at distances ranging from 10 to 40 miles from the base station. Heights of stations visited ranged from 100 feet to 500 feet.

The reduction of observations was carried out in the Computing Office on the form reproduced on page 99. The various entries in this form are self explanatory.

Before taking any observations with Paulin barometers they were compared with a standard barometer and index errors were determined. Similarly these index corrections were obtained on return from the field. The mean of both sets of errors for the particular time and pressure of both the field and base barometers are entered in column 3(*c*).

Table 1 gives discrepancies between the heights by Paulin's barometer and spirit-levelling in Rānīganj area in season 1947–48. The results of the observations in the Nāgpur area have not been completed yet.

Out of 28 stations two disclose discrepancies of —30 feet and +20 feet which are undoubtedly too high and are possibly due to certain local shocks which probably affected the index corrections; at 13 stations these range between 6 and 13 feet and at 13 stations the discrepancies are less than 5 feet. This was the very first year of experiment with the Paulin barometers and better results are expected with the experience gained.

The following routine in observing the Paulin Aneroid is suggested for future work :—

(i) Make one of the stations of the previous circuit as the *base* station for the second circuit.

(ii) A battery of 3 instead of 2 aneroids both at the base and at the field is suggested to help in spotting erroneous readings.

Hygrometers should be taken to the field stations also.

(iii) One base observer should observe every 20 minutes instead of the usual half-hour. Both observers should synchronize their watches before starting and after closing the work each day.

(iv) These instruments require very careful handling particularly in transportation otherwise the index errors change considerably resulting in loss of accuracy. A careful watch on the index errors should be kept by taking readings of all the six aneroids at the beginning and close of a day's work.

TABLE 1.—*Heights by Paulin Barometers in Rānīganj Area*

Starting point Rānīganj S.B.M. No. 342

1 Serial No.	2 Gravity Station No.	3 Corrected Paulin heights in feet	4 Spirit-levelling heights in feet	5 Difference Col. 4—Col. 3 in feet	REMARKS
1	73 I G 1 ..	470	440	−30	Possible due to certain local shocks which should have affected the index corrections.
2	73 I G 2 ..	640	660	+20	
3	73 M G 1 ..	388	388	0	
4	73 M G 2 ..	347	341	− 6	
5	73 M G 3 ..	385	396	+11	
6	73 M G 4 ..	327	314	−13	
7	73 M G 5 ..	312	306	− 6	
8	73 M G 6 ..	252	245	− 7	
9	73 M G 7 ..	186	192	+ 6	
10	73 M G 8 ..	168	162	− 6	
11	73 M G 9 ..	200	189	−11	
12	73 M G 10 ..	353	345	− 8	
13	73 M G 11 ..	198	191	− 7	
14	73 M G 12 ..	211	210	− 1	
15	73 M G 13 ..	101	105	+ 4	
16	73 M G 14 ..	260	257	− 3	
17	73 M G 15 ..	325	319	− 6	
18	73 M G 16 ..	132	128	− 4	
19	73 M G 17 ..	119	122	+ 3	
20	73 M G 18 ..	111	108	− 3	
21	73 M G 19 ..	148	139	− 9	
22	73 M G 20 ..	257	260	+ 3	
23	73 M G 21 ..	166	160	− 6	
24	73 M Rājband B.M. ..	218	218	0	
25	73 M Būd Būd B.M. ..	177	177	0	
26	73 M Burdwān B.M. ..	96	98	+ 2	
27	73 M Pānagar	236	238	+ 2	
28	73 M Kulgaria ..	122	118	− 4	

Date :—22-11-1947 | REDUCTION OF PAULIN ANEROID HEIGHTS | Height of Base Station =324 ft. | 13 S.R.I.

(1) Station (i)		(2) Time	(3) Aneroid Readings in feet: Aneroid No. 1769 (a)	Aneroid No. 2782 (b)	Mean (c)	(4) Index error in feet	(5) Corrected index col. 3(c)+col. (4)	(6) Corrn. from Table A below	(7) I.C.A.N. Heights col. (5)+col. (6)	(8) Observed temp. °F: Dry	Wet	(9) *Corrn. from Table B	(10) Corrected Temp. °F (ii)	(11) Relative Humidity % (iii)	(12) †Corrn. from Table C	(13) Heights col. (7)+col. (12)	(14) Accepted Height of Base Stn.	(15) Stn. Heights	(16) Adjustment Corrn.	(17) Final Height col. (15)+col. (16)	(18) Remarks
		h m							feet	°	°		°			feet	feet	feet	feet	feet	
73 M/G 4	F	11 00	270	310	290	+ 51	341	−68	273	78·2			78·2		+13	286		314	+10		Mean height of Būd Būd Camp = 179 ft.
(No. 2904)	S				284	+ 67	351	−68	283	78·2	64·0	0·0	78·2	42	+13	296	324				
Būd Būd Camp	F	12 30	182	208	195	+ 54	249	−69	180	60·0			81·9		+ 9	189		183	+ 2	185	
(No. 2904)	S				316	+ 66	382	−67	315	83·2	67·0	0·5	81·4	39	+15	330	324				
73 M/G 4	F	13 30	340	364	352	+ 50	402	−67	335	82·8			82·8		+17	352		329	− 5		
(No. 2904)	S				332	+ 65	397	−67	330	82·8	65·0	0·0	82·8	34	+17	347	324				
73 M/G 4	F	11 00	270	310	290	+ 51	341	−68	273	78·2			78·1		+13	286		396	−72		
(No. 2927)	S				148	+127	275	−69	206	78·2	64·0	0·3	78·4	42	+ 8	214	324				
Būd Būd Camp	F	12 30	182	208	195	+ 54	249	−69	180	80·0			81·7		+ 9	189		255	−81	174	
(No. 2927)	S				188	+125	313	−68	245	83·2	67·0	0·2	81·5	39	+13	258	324				
73 M/G 4	F	13 30	340	364	352	+ 50	402	−67	335	82·8			82·6		+17	352		414	−90		
(No. 2927)	S				101	+126	317	−68	249	82·8	65·0	0·4	83·0	34	+13	262	324				

(i) F=Field Barometer; S=Standard Barometer at Base Station.

(ii) Half of Col. 9 is added/subtracted to mean of observed dry bulb temperatures and entered against the lesser/greater height in Col. 5.

(iii) From 39 and 40 Sur. Aux. Tables Part III (Humidity Tables).

* For a Standard fall of temperature for a given difference of height (The War Office Aneroid Tables).

† Temp. and Humidity Correction (The War Office Aneroid Tables).

TABLE A (feet) Correction to reduce Paulin readings to I. C. A. N. terms.

Height	Corrn.	Height	Corrn.	Height	Corrn.	Height	Corrn.
− 27		362		875		2393	
45	−72	448	−67	1000	−62	2675	−59
121	−71	542	−66	1156	−61	2860	−60
197	−70	646	−65	1350	−60	3013	−61
276	−69	750	−64	1643	−59	3145	−62
362	−68	875	−63	2393	−58		

89. **Miscellaneous.**—The results of the High Precision Levelling from Bombay to Kolhāpur via Ratnāgiri, which has been completed in both directions (see Chapter II, paras 11 and 18) have been computed. Until the new high precision level net is complete, it has been decided to retain unaltered the published values of standard and primary bench-marks of the old 1909 Precision level net and to fit the lines of the new H.P. lines in between these bench-marks. There is no old standard or primary protected bench-mark at Kolhāpur. The new line cannot be adjusted until the line from Kolhāpur to Belgaum has been levelled in the back direction during the coming field season. The fore-levelling has been carried out during the period under report.

Results have also been computed of the precision levelling carried out from Hoshangābād to Mhow for the Executive Engineer lower Narbada Division (Chapter II, para 21).

Large scale surveys for the development of the Port of Kandla are likely to be taken up in the near future by the Southern Circle. Existing framework data triangulation has been examined for accuracy and sufficiency. It has been found that there is no *pakka* geodetic triangulation in the area. Series No. 35 and 39, which provide the G.T. data are of a secondary quality and are connected to the good quality Karāchi Longitudinal Series No. 25 through another secondary series (Kāthiāwār Meridional No. 28). It thus appears necessary to strengthen the G.T. framework by the introduction of a new geodetic base of high accuracy near the junction of Series Nos. 28 and 35 and to observe two twin Laplace stations in Series No. 35. The old data of topographical triangulation carried out in 1882-83 is practically non-existent now and supplementary topographical triangulation to provide points for new surveys is necessary. A party under Mr. U. D. Mamgain has reconnoitred the area and a detailed programme of geodetic triangulation has been prepared, which will be given effect to during the next field season, thus making a start with the revision of triangulation of secondary quality, which is nearly a century old now.

Gravity anomalies have been computed at stations observed with the gravimeter in Rānīganj and Nāgpur areas (see Chapter III, para 33) and at a number of stations in Siam (Chapter III, para 40).

Chapter VIII

RESEARCH AND TECHNICAL NOTES

BY B. L. GULATEE, M.A. (CANTAB.)

Section I. Mean Sea-Levels in India

1. A number of countries have, of late, been paying increased attention to the study of the Mean Sea-Level (M.S.L.) and its fluctuations, and of the multifarious geophysical problems associated with such fluctuations. Various scientific bodies, notably the International Association of Physical Oceanography, and others interested in the subject have been frequently asking the Survey of India for monthly and annual values of the M.S.L. at Indian ports, as obtained from systematic tidal observations, for quantitative analysis and research on various problems. Tables 1 and 2 show respectively the values of the monthly and annual M.S.L. at various ports in the Indian Ocean, as far as have been computed. Most of these computed values have been supplied to the International Hydrographic Bureau, who have been compiling world-wide data of this type, and some of these have already been published by the International Association of Physical Oceanography in their "Publication Scientifique No. 5" and its supplementary annual lists for 1937 and 1938.

2. The table of annual values (i.e., Table 2) comprises three different kinds of data, viz :

(i) Accurate yearly means, computed rigorously from hourly heights for the period 1st Jan. to 31st Dec. of every year with the incomplete tidal periods ignored,

(ii) approximate yearly means (A_0) computed from hourly heights for 370 consecutive days, as obtained in the course of harmonic analysis of tidal observations,

and (iii) still less accurate yearly means called Mean Tide Level or M.T.L. computed from the mean observed high and low waters of each year (Jan. to Dec.).

For a number of ports, observational data exist for years subsequent to 1920 but it has not been possible, due to shortage of personnel, to compute the M.S.L. results from hourly heights. The data are mostly in the form of tide-gauge charts, the hourly heights from which need reading and proper summing up—a fairly laborious task. Even for the years up to 1920 for which hourly heights have been read in the course of harmonic analysis, it has not been possible to compute the M.S.L. results rigorously as in method (i) by calculating the annual means (1st Jan. to 31st Dec.), and the means of 370 days' observations have had to be accepted. A synopsis of the tidal data available for M.S.L. computations is given in Table 3.

Though the values given in Tables 1 and 2 may suffice for a preliminary investigation of M.S.L. changes, it is essential to obtain accurate figures before any final interpretation of such changes can be attempted. The M.T.L. values are comparatively easy to obtain, but may differ considerably from the local M.S.L. values, especially at places situated up the river estuaries. Furthermore, changes in the M.T.L. primarily depend on changes in the tidal regime (which occur frequently due to local causes like siltation, formation of bars, dredging, etc.) and may have no proportionate relation to the changes in the actual local M.S.L. Conclusions about M.S.L. changes, based on M.T.L. values, are, therefore, apt to be unreliable.

3. It is worth mentioning that the M.S.L. results derived from systematic observations at different ports for a sufficient number of years are of great value for

(i) obtaining a reliable datum for the geodetic level net of a country,

(ii) deciphering vertical movements of the land and investigating the coastal stability,

(iii) studying the fluctuations of the sea-level in relation to meteorological conditions,

and (iv) detecting eustatic changes in the sea-level (due to glaciation and other factors) by comparison with similar observations in other countries, and helping many geoidal investigations.

The question of constancy of sea-level is of particular interest to the geodesist since this surface (imagined extended under the land) is the geoid to which all land heights are referred and to which the figure of the earth adopted for map projections is to be closely fitted. The changes in the sea-level, whether eustatic or only local (due to rise or subsidence of land), generally take place only in the course of some years, and in order to detect their trend and extent, very accurate and systematic observations extending over a number of years are required.

4. Plate XXXI shows the plotted graphs of the monthly and annual M.S.L. values for the major ports in the Indian Ocean, at which systematic and continuous observations have been carried out for over 19 years. The plate also shows the respective smoothed graphs of the annual M.S.L. values plotted from 9-yearly moving means. Table 4 gives the values of these means.

Progressive changes of mean sea-level relative to the land are noticeable in Port Blair and Calcutta. There is an upward trend of the M.S.L. at Bombay from 1930 onwards, but these values are not rigorously derived and are based on only High and Low waters. The Calcutta results are discussed in detail in the next section.

MEAN SEA — LEVELS AT INDIAN PORTS.

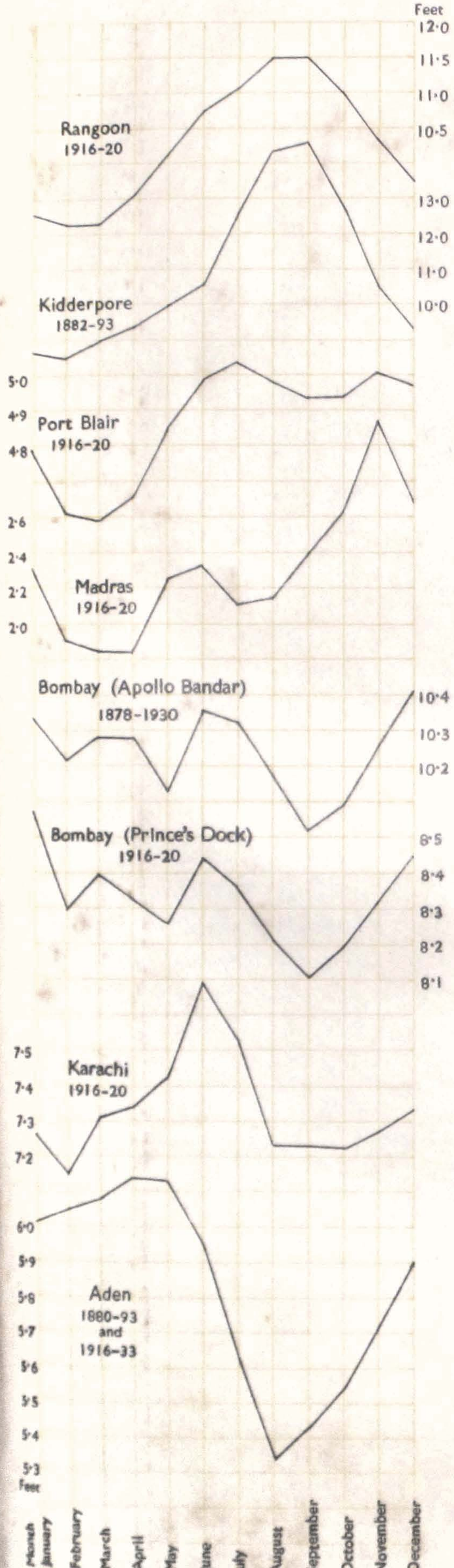


Fig. 1. Average monthly means.

R.S.No.601M/NCD'50(G&T.C.)-375.

Fig. 2. Yearly means.

Printed at the Survey of India Offices, (P. Z. O.).

TABLE 1.—*Monthly Mean Heights of Sea-Level*

ADEN

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1879	..	..	6·083	6·207	6·149	5·869	5·557	5·304	5·387	5·454	5·600	5·787
1880	5·733	6·086	6·021	6·070	6·078	5·942	5·621	5·262	5·370	5·472	5·552	5·858
1881	6·033	6·093	6·096	6·046	6·189	5·819	5·823	5·355	5·402	5·476	5·720	5·897
1882	5·865	6·079	6·098	6·115	6·058	5·690	5·323	5·412	5·486	5·386	5·580	5·917
1883	6·023	5·968	6·001	6·114	6·111	5·836	5·429	5·405	5·429	5·534	5·745	5·873
1884	6·114	5·992	6·058	6·109	6·231	5·911	5·620	5·499	5·407	5·516	5·668	5·973
1885	6·088	6·074	6·159	6·247	6·254	6·179	5·688	5·429	5·243	5·472	5·793	5·932
1886	6·075	6·115	6·198	6·194	6·329	6·198	5·834	5·450	5·371	5·589	5·687	5·830
1887	6·184	5·946	6·063	6·046	6·198	5·860	5·542	5·318	5·320	5·476	5·788	6·025
1888	6·078	6·142	5·998	6·153	6·131	5·958	5·682	5·517	5·459	5·599	5·889	5·833
1889	6·042	6·049	6·155	6·143	6·131	5·872	5·675	5·301	5·520	5·551	5·628	5·921
1890	6·016	6·081	6·147	6·189	6·221	5·860	5·459	5·224	5·467	5·417	5·687	5·927
1891	5·868	6·014	6·131	6·184	6·167	5·879	5·579	5·397	5·436	5·662	5·884	5·834
1892	5·918	6·086	5·922	6·237	6·171	6·045	5·594	5·339	5·561	5·616	5·714	5·846
1893	6·070	5·996	6·175	6·172	6·041	5·966	5·747	5·357	5·290	5·421	5·476	5·966
					Results not computed							
1916	6·17	6·23	6·18	6·24	6·15	6·04	5·64	5·19	5·53	5·56	5·85	6·05
1917	6·11	6·09	5·96	6·17	6·01	5·88	5·55	5·45	5·28	5·58	5·53	5·91
1918	6·06	6·23	6·03	6·16	5·90	5·84	5·70	5·39	5·41	5·60	6·04	5·89
1919	5·92	6·11	6·07	6·09	6·21	5·94	5·69	5·30	5·48	5·56	5·74	5·98
1920	6·10	6·08	6·21	6·24	6·12	6·04	5·63	5·44	5·42	5·58	5·72	5·89
1921	5·98	5·95	6·02	6·15	6·26	6·09	5·65	5·24	5·45	5·57	5·81	5·92
1922	6·03	6·16	6·06	6·25	6·26	6·07	5·58	5·23	5·42	5·59	5·63	5·85
1923	6·10	6·14	6·17	6·15	6·05	5·95	5·54	5·19	5·52	5·53	5·78	5·92
1924	5·98	5·97	6·04	6·14	6·11	6·13	5·55	5·38	5·51	5·54	5·61	5·82
1925	5·98	5·95	6·10	6·07	6·21	5·89	5·57	5·32	5·57	5·65	5·90	6·06
1926	6·03	5·99	6·06	6·20	6·19	6·09	5·77	5·32	5·47	5·60	5·83	5·75
1927	6·04	6·08	6·07	6·10	6·08	5·96	5·54	5·42	5·47	5·57	5·78	5·95
1928	6·08	5·95	6·05	6·09	6·07	5·92	5·66	5·35	5·41	5·57	5·75	5·90
1929	5·92	6·03	6·07	6·10	6·13	5·88	5·51	5·17	5·46	5·54	5·76	5·84
1930	6·09	6·07	6·04	6·14	6·05	5·92	5·53	5·29	5·45	5·52	5·67	5·86
1931	5·96	6·17	6·14	6·13	6·20	6·13	5·79	5·30	5·56	5·46	5·71	5·93
1932	5·95	5·97	6·07	6·06	6·05	5·88	5·66	5·46	5·50	5·69	5·74	6·06
1933	6·13	6·15	6·20	6·26	6·14	6·01	5·66	5·41	5·39	5·67	5·69	5·87
					Results not computed							
1937	4·68	4·60	4·68	4·80	4·62	4·47	4·17	3·76	4·03	4·08	4·30	4·32
1938	4·47	4·48	4·45	4·69	4·61	4·38	3·98	..	..	..	..	..
1939	..	..	..	..	..	4·45	4·18	3·99	3·97	4·08	4·29	..
1940	4·57	4·62	4·70	4·77	4·78	4·63	4·12	3·88	4·13	4·21	4·56	4·50
1941	4·50	4·68	4·65	4·86	4·79	4·63	4·34	4·10	4·06	4·36	4·54	4·60
1942	4·72	4·74	4·81	4·88	4·88	4·70	4·16	4·16	4·08	4·15	4·31	4·40
1943	4·38	4·73	4·78	4·66	4·80	4·55	4·19	3·94	3·91	4·12	4·36	4·54
1944	..	..	..	..	4·75	4·49	4·17	3·97	3·92	4·15	4·41	4·67
1945	4·72	4·69	..	..	4·86	4·70	4·26	4·17	4·11	..	4·27	4.53
1946	4·61	4·68	4·80	4·87	4·71	4·68	4.39	3.59	3·86	3·86	4·13	4·29
1947	4·62	4·64	4·60	4·74	4·86	4·64	4·49	4·19	4·07	4·08	4.42	4·58
1948	4·67	4·78	4·76	4·98	4·88	4·74	4·23	4·06	4·06	4·28	4·54	4·56
Average for 1880–93 and 1916–33 (32 yrs.)	6·02	6·03	6·09	6·15	6·14	5·96	5·62	5·35	5·41	5·55	5·73	5·91

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly Mean Heights of Sea-Level*—(contd.)

BASRAH

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1917	5·838	6·427	6·474	7·485	7·497	6·822	6·476	5·969	5·359	5·000	4·898	5·113
1918	5·194	5·601	6·546	7·300	8·612	8·413	7·385	6·219	5·691	5·579	5·642	5·566

KARACHI

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1916	7·35	7·03	7·28	7·35	7·33	7·65	7·72	7·39	7·36	7·28	7·25	7·51
1917	7·45	7·37	7·28	7·49	7·37	7·73	7·28	7·20	7·25	7·37	7·23	7·48
1918	7·21	7·19	7·43	7·24	7·69	7·82	7·47	7·19	7·11	7·25	7·33	7·15
1919	7·06	7·01	7·10	7·07	7·47	7·42	7·57	7·23	7·18	7·14	7·15	7·55
1920	7·26	7·18	7·49	7·59	7·27	7·86	7·67	7·31	7·31	7·13	7·46	7·01
				Results not computed								
1937	5·51	5·38	5·38	5·60	5·43	5·70	5·62	5·45	5·28	5·36	5·63	5·35
1938	5·25	5·12	5·39	5·57	5·64	5·86	5·53	5·54	5·34	5·18	5·53	5·45
1939	5·28	5·30	5·36	5·42	5·35	5·84	5·43	5·09	5·31	5·14	5·29	5·53
1940	5·42	5·18	5·13	5·45	5·56	5·84	5·50	5·39	5·18	5·46	5·63	5·46
1941	5·33	5·29	5·36	5·44	5·77	5·79	5·45	5·48	5·27	5·33	5·60	5·39
1942	5·28	5·31	5·47	5·39	5·52	5·41	5·60	5·40	5·29	5·34	5·53	5·54
1943	5·45	5·52	5·35	5·35	5·41	5·45	5·03	5·14	4·98	4·88	5·11	5·40
1944	5·12	4·97	5·09	5·08	5·19	5·37	5·62	5·62	5·31	5·20	5·45	5·29
1945	5·32	5·20	5·34	5·26	5·73	5·15	5·22	5·67	5·32	5·16	5·14	5·52
1946	5·15	5·39	5·44	5·67	5·60	6·24	5·59	5·42	5·07	5·00	5·04	4·76
1947	..	5·33	5·19	5·30	5·49	5·31	5·53	5·72	5·14	5·05	5·54	5·42
1948	5·37	4·87	..	Data not available				..	..	..	..	..
Average for 1916–20 (5 yrs.)	7·27	7·16	7·32	7·35	7·43	7·70	7·54	7·24	7·24	7·23	7·28	7·34

BHAVNAGAR

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937	19·15	18·90	18·83	19·19	19·35	20·34	21·08	21·00	20·70	20·08	19·80	19·28
1938	19·03	18·60	18·83	19·19	19·40	19·94	20·35	20·80	20·65	20·27	20·04	19·58
1939	19·21	19·05	18·73	19·17	19·19	20·04	20·54	20·26	20·49	20·05	19·52	19·63
1940	19·46	19·01	18·66	19·07	19·42	19·93	20·36	20·74	20·33	20·13	19·92	19·35
1941	19·10	18·89	18·94	19·47	19·97	20·09	20·43	20·62	20·36	20·01	19·99	19·63
1942	19·13	18·84	18·74	18·86	19·35	19·63	20·23	20·63	20·57	20·10	19·68	19·27
1943	19·26	19·04	19·12	19·26	19·39	19·50	20·18	20·42	20·66	20·36	20·29	19·95
1944	19·73	19·23	19·48	19·76	20·12	20·38	20·79	21·99	21·64	21·13	21·16	20·29
1945	19·95	19·40	19·30	19·44	19·61	20·19	20·66	21·64	21·41	21·24	20·52	19·83
1946	19·02	19·24	19·14	19·66	19·93	20·48	20·97	21·52	21·39	20·85	20·22	19·49
1947	19·31	19·68	19·66	20·17	20·25	20·48	21·02	21·53	21·60	21·42	21·13	19·60
1948	20·14	19·39	19·31	19·16	..	20·00	19·88	20·63	21·21	21·28	20·43	19·79
Average for 1937–48 (12 yrs.)	19·37	19·11	1 ·06	19·37	19·63	20·08	20·54	20·98	20·92	20·58	20·23	19·64

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly Mean Heights of Sea-Level*—(contd.)

BOMBAY (Apollo Bandar)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1878	9·92	10·19	10·19	10·27	10·34	10·28	10·60	10·61	10·35	10·22	10·13	10·07
1879	10·38	10·37	10·09	10·11	10·23	10·12	10·13	10·25	9·92	9·93	10·12	10·42
1880	10·24	10·18	10·45	10·19	10·13	10·04	10·23	9·88	10·02	10·03	10·31	10·47
1881	10·63	10·55	10·33	10·15	10·26	9·91	10·44	10·13	10·06	9·83	10·30	10·46
1882	10·44	10·27	10·35	10·38	9·94	10·37	10·44	9·93	9·92	9·94	10·13	10·28
1883	10·37	10·23	10·19	10·12	10·17	10·46	10·39	10·03	10·17	10·16	10·35	10·40
1884	10·40	10·28	10·27	10·16	10·28	10·30	10·33	10·10	10·23	10·02	10·24	10·41
1885	10·51	10·14	10·34	10·34	10·15	10·62	10·20	10·49	10·13	10·37	10·15	10·25
1886	10·28	10·12	10·32	10·23	10·57	10·45	10·30	10·02	9·99	10·19	10·19	10·51
1887	10·38	10·17	10·24	10·13	10·05	10·36	10·30	10·15	9·76	10·09	10·12	10·67
1888	10·49	10·30	10·29	10·17	10·12	10·45	10·37	10·21	9·82	10·15	10·35	10·28
1889	10·21	10·21	10·24	10·29	10·09	10·33	10·29	10·10	10·00	10·08	10·18	10·43
1890	10·51	10·30	10·21	10·19	10·02	10·54	10·44	10·12	10·14	9·83	10·22	10·39
1891	10·36	10·05	10·24	10·26	10·03	9·97	10·29	10·22	9·96	10·03	10·20	10·22
1892	10·18	10·15	10·21	10·37	10·07	10·50	10·57	10·22	10·19	10·21	10·29	10·43
1893	10·39	9·99	10·38	10·34	9·93	10·50	10·19	10·15	9·92	9·95	10·26	10·56
1894	10·43	10·36	10·13	10·37	9·97	10·36	10·29	10·14	9·97	10·26	10·06	10·48
1895	10·25	10·19	10·28	10·34	9·89	10·37	10·16	10·15	9·76	10·24	10·34	10·37
1896	10·40	9·95	10·26	10·37	10·11	10·63	10·36	10·41	9·95	10·06	10·28	10·04
1897	10·07	10·17	10·09	10·32	10·13	10·38	10·55	10·45	10·16	10·09	10·25	10·36
1898	10·40	10·29	10·45	10·37	10·08	10·54	10·41	10·11	10·07	10·23	10·43	10·66
1899	10·35	10·31	10·41	10·54	10·13	10·33	10·02	9·91	9·72	10·13	10·17	10·35
1900	10·11	10·10	10·10	10·31	9·97	10·16	10·05	10·50	9·90	9·94	10·44	10·44
1901	10·25	10·12	10·41	10·63	10·14	10·23	10·26	10·28	9·75	9·95	10·30	10·41
1902	10·38	10·39	10·42	10·41	10·12	10·48	10·21	10·06	10·22	10·32	10·36	10·38
1903	10·25	10·05	10·09	10·32	10·36	10·61	10·53	10·35	10·07	10·15	10·39	10·60
1904	10·47	10·50	10·39	10·17	10·13	10·27	10·11	10·01	9·85	10·00	10·08	10·33
1905	10·12	9·85	9·88	9·84	10·12	10·16	10·17	10·03	10·02	10·12	10·15	10·34
1906	10·00	10·03	9·99	10·02	10·09	10·46	10·33	10·05	10·11	10·08	10·14	10·35
1907	10·44	10·16	10·19	10·49	9·96	10·34	10·11	10·25	9·83	9·97	10·05	10·38
1908	10·34	10·22	10·19	10·37	9·84	10·20	10·24	10·21	9·90	9·89	10·09	10·29
1909	10·31	10·10	10·33	10·25	10·00	10·36	10·48	9·92	9·97	9·85	10·13	10·34
1910	10·37	10·16	10·27	10·12	10·07	10·35	10·21	10·20	10·08	10·01	10·21	10·40
1911	10·45	10·23	10·28	9·82	10·20	10·16	10·05	10·22	9·94	10·02	10·49	10·33
1912	10·31	10·26	10·13	10·44	10·18	10·43	10·33	10·25	10·08	10·09	10·45	10·66
1913	10·26	10·28	10·05	10·34	10·34	10·41	10·43	9·98	9·84	10·03	10·17	10·14
1914	10·35	10·09	10·03	10·12	10·12	10·49	10·23	10·13	10·24	10·30	10·49	10·42
1915	10·44	10·35	10·38	10·28	10·06	10·30	10·33	10·04	10·00	10·20	10·18	10·53
1916	10·52	10·08	10·41	10·24	10·17	10·42	10·54	10·39	10·27	10·18	10·32	10·60
1917	10·64	10·46	10·29	10·31	10·10	10·44	10·15	10·21	10·25	10·44	10·14	10·50
1918	10·50	10·33	10·58	10·22	10·36	10·40	10·18	10·05	9·93	10·19	10·42	10·26
1919	10·31	10·16	10·11	9·96	10·23	10·07	10·21	10·04	9·95	9·90	10·12	10·59
1920	10·52	10·30	10·42	10·48	10·00	10·54	10·45	10·08	10·00	9·97	10·41	10·18
1921	10·22	10·31	10·29	10·43	10·11	10·26	10·37	10·39	10·14	10·17	10·45	10·53
1922	10·34	10·30	10·25	10·54	10·34	10·46	10·33	10·12	10·02	9·88	10·16	10·22

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3. (*contd.*)

TABLE 1.—*Monthly Mean Heights of Sea-Level*—(contd.)

BOMBAY (Apollo Bandar)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1923	10·40	10·17	10·43	10·18	9·88	9·97	10·39	10·45	9·86	9·86	9·82	10·24
1924	10·14	10·29	10·37	10·31	10·19	10·62	10·48	10·16	10·08	10·01	10·00	10.56
1925	10·19	10·19	10·38	10·39	10·21	10·46	10·12	10·03	9·96	10·20	10·47	10·33
1926	10·27	10·27	10·21	10·22	10·30	10·25	10·57	10·43	10·33	9·95	10·23	10·37
1927	10·18	10·12	10·15	10·11	10·10	10·38	10·23	10·31	10·13	10·19	10·28	10·47
1928	10·25	10·17	10·26	10·18	10·30	10·02	10·37	10·19	9·97	9·91	10·32	10·46
1929	10·29	10·29	10·65	10·50	10·14	10·56	10·43	9·96	10·09	10·27	10·53	10·37
1930	10·39	10·09	10·38	10·55	10·02	10·73	10·37	10·11	10·03	10·09	10·33	10·43
1931	10·72	10·42	10·46	10·41	10·25	10·43	10·64	10·61	10·04	10·20	10·40	10·70
1932	10·77	10·45	10·48	10·26	10·34	10·32	10·60	10·45	10·23	10·48	10·30	10·35
1933	10·52	10·41	10·45	10·45	10·46	10·79	10·32	10·41	10·33	10·43	10·64	10·79
1934	10·54	10·54	10·56	10·58	10·25	10·52	10·47	10·51	10·10	10·06	10·48	10·75
1935	10·38	10·45	10·42	10·39	10·29	10·32	10·41	10·25	10·10	10·35	10·11	10·53
1936	10·27	10·41	10·37	10·31	10·23	10·70	10·29	10·02	10·08	9·92	10·65	10·78
1937	8·58	8·46	8·44	8·73	8·29	8·57	8·67	8·38	8·26	8·34	8·67	8·51
1938	8·64	8·44	8·47	8·57	8·42	8·63	8·55	8·49	8·28	8·33	8·65	8·78
1939	8·69	8·47	8·59	8·43	8·13	8·60	8·48	8·12	8·31	8·19	8·27	8·78
1940	8·64	8·30	8·30	8·60	8·47	8·72	8·47	8·50	8·27	8·54	8·81	8·67
1941	8·54	8·48	8·46	8·48	8·59	8·50	8·40	8·41	8·03	8·29	8·62	8·54
1942	8·44	8·33	8·68	8·43	8·27	8·38	8·71	8·52	8·30	8·19	8·44	8·54
1943	8·66	8·58	8·63	8·42	8·59	8·56	8·54	8·32	8·26	8·23	8·47	8·84
1944	8·68	8·32	8·50	8·41	8·32	8·52	8·88	9·07	8·19	8·19	8·43	8·51
1945	8·59	8·28	8·24	8·42	8·33	8·64	8·56	8·70	8·28	8·10	8·36	8·54
1946	8·43	8·65	8·40	8·49	8·11	8·91	8·59	8·75	8·18	8·35	8·56	8·48
1947	8·64	8·57	8·32	8·50	8·46	8·25	8·31	8·24	8·41	8·16	8·63	8·58
1948	8·72	8·47	8·60	8·67	8·45	8·54	8·43	8·43	8·38	8·47	8·55	8·76
Average for 1878-1930 (53 yrs.)	10·33	10·21	10·27	10·27	10·12	10·35	10·31	10·17	10·01	10·08	10·25	10·40

BOMBAY (Prince's Dock)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1916	8·71	8·11	8·40	8·22	8·21	8·45	8·52	8·39	8·25	8·30	8·50	8·76
1917	8·84	8·59	8·34	8·36	8·15	8·51	8·20	8·26	8·20	8·45	8·14	8·53
1918	8·50	8·35	8·56	8·22	8·34	8·43	8·22	8·11	8·00	8·20	8·44	8·26
1919	8·33	8·17	8·27	8·46	8·72	8·34	8·45	8·31	8·20	8·14	8·21	8·66
1920	8·54	8·33	8·45	8·46	7·95	8·52	8·45	8·02	7·95	7·89	8·34	8·06
Average for 1916-20	8·58	8·31	8·40	8·34	8·27	8·45	8·37	8·22	8·12	8·20	8·33	8·46

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly Mean Heights of Sea-Level*—(contd.)

COLOMBO

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1934	1·49	1·56	1·47	1·51	1·17	1·10	0·87	0·93	0·84	1·12	1·53	1·78
1935	1·45	1·48	1·41	1·49	1·21	0·94	0·76	0·96	0·98	1·25	1·16	1·53
Average for 1934-35	1·47	1·52	1·44	1·50	1·19	1·02	0·82	0·95	0·91	1·19	1·35	1·06

MADRAS

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1916	2·11	1·90	1·81	2·05	2·38	2·60	2·42	2·24	2·65	2·85	3·09	2·70
1917	2·31	2·12	2·06	2·05	2·08	2·19	2·02	2·29	2·44	2·71	3·36	2·68
1918	2·58	1·94	1·68	1·59	2·20	2·16	1·89	1·83	2·32	2·54	3·22	2·68
1919	2·18	1·75	1·76	1·73	2·39	2·55	2·08	2·15	2·26	2·55	3·27	2·94
1920	2·50	1·92	2·04	1·89	2·35	2·22	2·17	2·29	2·44	2·67	2·85	2·46
Average for 1916-20	2·34	1·93	1·87	1·86	2·28	2·34	2·12	2·16	2·42	2·66	3·16	2·69

VIZAGAPATAM

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937	2·17	2·00	1·74	1·92	2·50	2·69	2·48	2·56	3·01	3·31	3·19	3·16
1938	2·33	1·95	2·09	2·20	2·74	2·92	2·87	2·71	2·72	3·35	3·16	2·60
1939	2·54	2·01	1·81	1·77	2·56	2·66	2·46	2·75	2·64	3·29	3·42	2·91
1940	2·04	1·65	1·56	1·98	2·60	2·72	2·40	2·60	2·73	3·10	3·49	2·93
1941	2·16	1·88	1·63	2·02	2·50	2·84	2·44	2·76	2·67	3·16	3·11	2·91
1942	2·25	1·88	1·73	1·97	2·24	2·81	2·65	2·76	3·14	3·39	3·39	2·52
1943	2·36	2·01	1·95	2·21	2·50	2·87	2·86	2·66	3·19	3·48	3·38	2·82
1944	2·03	1·92	2·03	1·87	2·29	2·54	2·43	2·26	2·70	3·29	3·09	2·89
1945	2·45	2·03	2·01	2·26	2·53	2·54	2·57	2·56	3·26	3·39	3·18	2·83
1946	2·26	1·96	1·58	2·19	(break)		2·49	2·51	2·41	2·91	3·02	3·02
1947	2·48	1·97	1·93	2·03	1·84	2·21	2·42	2·80	3·19	3·86	3·53	2·94
1948	2·49	2·04	1·94	2·15	2·70	2·85	2·72	2·96	2·95	3·08	3·60	2·86
Average for 1937-48 (12 yrs.)	2·30	1·94	1·83	2·05	2·45	2·70	2·57	2·66	2·88	3·30	3·30	2·87

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly Mean Heights of Sea-Level*—(contd.)

DUBLAT (1881-86)

SAUGOR (1933-48)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1881	..	..	..	..	9·73	10·30	10·15	10·19	10·17	..	9·87	9·21
1882	9·11	8·62	8·76	8·95	9·59	10·06	10·06	10·15	10·58	10·51	9·88	9·48
1883	8·77	8·50	8 69	9·15	9·63	10·01	10·29	10·25	10·29	9·98	9·89	9·61
1884	8·72	8·59	8·68	9·07	9·76	10·13	10·38	10·46	10·24	9·76	9·73	9·45
1885	8·65	8·49	8·67	9·00	9·23	10·07	10·03	9·92	10·12	9·99	9·67	9·12
1886	8·91	8·53	8·61	..	..	..	..	..	..	..	..	..
	Saugor values 1933–36 not computed											
1937	9·20	8·82	8·77	9·06	9·95	10·38	10·56	10·31	10·68	10·33	9·76	9·73
1938	9·02	8·67	9·00	9·20	9·92	10·55	10·60	10·47	10·30	10·47	9·83	9·25
1939	9·24	8·82	8·72	8·91	9·90	10·03	9·87	10·71	10·29	10·45	10·22	9·71
1940	8·98	8·73	8·82	9·13	10·06	10·16	10·23	10·20	9·91	9·81	9·96	9·41
1941	8·63	8·47	8·50	9·10	9·80	10·39	9·89	10·39	10·13	10·27	9·71	9·68
1942	8·94	8·67	8·65	9·04	9·63	10·45	10·38	10·18	10·58	9·96	10·06	9·26
1943	9·15	8·58	9·00	9·28	9·68	10·07	10·27	10·08	10·52	..	..	..

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly mean heights of Sea-Level*—(contd.)

KIDDERPORE

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1881	..	..	8·498	9·210	9·873	10·635	12·183	14·241	14·381	12·953	10·321	8·979
1882	8·864	8·502	8·870	9·006	9·656	10·761	12·715	13·731	13·802	12·985	10·308	9·430
1883	8·622	8·436	8·919	9·578	10·070	10·634	12·127	13·961	13·433	11·532	10·058	9·512
1884	8·747	8·686	9·066	9·421	9·959	10·230	11·816	13·440	13·375	12·803	10·737	9·752
1885	8·838	8·533	9·115	9·171	9·475	10·370	12·562	14·803	15·769	12·701	10·386	9·326
1886	9·082	8·724	8·926	9·558	9·999	10·916	13·101	14·859	15·799	14·215	11·325	9·813
1887	9·098	8·888	9·362	9·723	10·646	11·550	12·890	14·409	14·841	12·641	10·462	9·485
1888	8·816	8·513	9·152	9·850	10·063	10·297	12·046	14·930	15·255	11·989	9·981	9·142
1889	8·993	8·449	8·967	9·470	10·283	10·923	13·061	14·380	15·469	12·968	11·225	9·779
1890	9·006	9·104	9·147	9·756	10·002	11·227	14·006	16·256	15·356	13·995	10·731	9·237
1891	8·577	8·526	8·872	9·454	9·946	10·997	11·799	13·726	13·952	12·133	10·407	9·075
1892	8·631	8·590	9·280	10·113	10·254	10·428	12·470	13·835	14·716	12·201	10·445	9·222
1893	8·644	8·216	8·838	9·575	10·395	11·413	14·099	14·899	15·010	13·552	11·102	9·869
				Results not computed								
1921	8·33	8·39	8·86	8·37	9·74	10·32	10·80	12·61	14·09	11·32	9·59	8·72
1922	8·39	8·29	8·80	9·39	9·99	10·90	12·59	14·18	14·09	12·35	9·77	9·16
1923	8·50	8·47	8·37	9·10	9·87	9·95	10·65	12·75	11·99	10·82	9·29	8·49
1924	8·50	8·28	8·57	9·36	9·82	10·34	11·38	13·00	13·91	12·18	10·20	9·18
1925	8·41	8·52	8·47	9·20	9·52	9·81	11·08	13·83	12·65	10·49	9·15	8·91
1926	8·35	8·11	8·46	8·75	9·40	9·96	10·71	12·98	13·60	11·14	9·51	8·80
1927	8·62	8·41	8·60	9·61	9·88	10·58	10·45	11·91	11·90	10·76	9·28	..
1928	..	..	(Break in observations)				..	12·51	11·96	11·57	9·83	8·80
1929	8·71	8·19	8·67	9·17	10·06	10·20	11·07	13·18	11·90	11·94	9·93	8·73
1930	8·05	8·18	8·71	9·13	9·93	10·22	11·39	13·03	12·44	11·02	9·98	8·84
1931	8·19	8·25	8·32	9·21	10·50	9·95	10·63	12·75	13·14	12·24	10·52	9·07
1932	8·66	8·28	8·46	9·07	9·20	9·82	10·41	11·76	11·89	10·47	9·90	8·85
1933	7·76	8·14	8·35	8·71	9·00	10·07	11·89	13·00	13·70	11·86	10·00	8·79
1934	8·24	8·28	8·38	9·20	9·33	9·34	10·98	12·42	12·90	11·02	9·55	8·41
1935	7·66	7·99	8·24	8·58	9·20	9·53	10·10	12·41	12·34	10·51	9·29	8·49
1936	8·07	8·19	8·28	9·03	9·42	10·12	11·32	13·30	13·83	12·35	9·90	8·74
1937	8·22	8·35	8·36	8·63	9·64	10·12	10·87	12·59	13·32	12·34	9·64	9·05
1938	8·29	8·01	8·78	9·19	9·70	10·92	12·54	14·28	14·24	11·63	9·64	8·71
1939	8·64	8·51	8·35	8·98	9·82	10·02	10·94	14·38	12·70	12·13	10·12	9·03
1940	8·19	8·04	8·41	8·72	9·70	10·10	10·63	12·24	12·14	10·29	9·69	8·88
1941	8·24	8·00	8·47	9·28	9·89	10·28	10·88	12·37	12·83	11·92	9·66	9·29
1942	8·45	8·33	8·64	9·24	9·86	10·37	11·28	13·53	14·44	12·24	10·23	8·79
1943	8·64	8·29	8·82	9·24	9·52	10·10	11·71	13·52	13·47	11·92	10·10	9·14
1944	8·17	8·12	8·42	8·66	9·81	9·71	10·94	12·59	12·23	11·01	9·47	8·99
1945	8·32	8·27	8·82	8·98	9·64	9·62	10·89	11·70	12·78	11·83	9·96	8·82
1946	8·20	8·23	8·36	8·96	9·59	9·90	11·51	12·73	13·24	11·70	9·82	9·04
1947	8·39	8·42	..	..	9·50	9·85	10·60	12·38	13·24	12·07	9·81	8·65
1948	8·35	8·27	8·42	9·35	9·96	9·95	11·00	12·78	13·26	11·93	10·22	8·03
Ave age for 1882-93 (12 yrs.)	8·83	8·60	9·04	9·47	10·06	10·73	12·72	14·44	14·73	12·81	10·60	9·47

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly Mean Heights of Sea-Level*—(contd.)

CHITTAGONG

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937	4·95	5·03	5·22	5·84	6·96	8·37	8·49	9·13	8·30	6·99	5·68	5·90
1938	5·11	4·92	5·78	6·18	7·44	9·71	8·90	8·83	8·79	7·60	6·37	5·36
1939	5·28	5·18	5·31	6·16	7·19	8·00	8·67	9·09	8·01	7·11	6·39	5·56
1940	5·04	5·11	5·49	5·96	7·06	8·21	8·49	8·86	8·45	7·17	6·34	5·59
1941	5·10	5·09	5·44	6·34	7·43	9·12	9·43	8·83	8·05	7·37	6·13	5·77
1942	5·12	5·04	..	..	..	..	(Data not available)			..	..	..
1943	..	5·22	5·70	6·13	6·86	8·16	8·66	8·79	8·39	7·09	6·28	5·60
1944	4·75	4·79	5·12	5·62	6·85	7·85	8·50	8·27	7·71	6·69	5·77	5·25
1945	4·80	4·73	5·21	5·84	7·02	8·25	8·55	9·12	8·36	7·09	6·40	5·64
1946	4·76	4·78	5·18	5·96	7·18	8·38	9·63	9·16	8·08	7·10	6·03	5·46
1947	4·85	4·74	5·35	6·29	6·98	8·88	9·53	9·54	8·59	7·25	6·65	5·20
1948	4·52	4·55	..	..	..	..	(Data not available)			..	..	..
Average for 1937-48 (12 yrs.)	4·93	4·93	5·38	6·03	7·10	8·39	8·89	8·96	8·27	7·15	6·20	5·53

AKYAB

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1937	3·21	3·18	3·29	3·80	4·63	5·27	5·47	5·18	4·89	4·50	4·01	4·08
1938	3·38	3·34	3·62	4·41	5·16	5·74	5·64	5·25	4·93	4·85	4·22	3·63
1939	3·63	3·30	3·32	3·82	4·66	5·48	5·55	5·57	4·85	4·65	4·50	3·84
1940	3·14	2·89	3·44	3·89	4·65	5·36	5·27	5·20	4·77	4·48	4·33	3·96
1941	3·35	3·12	3·40	4·06	4·99	5·68	5·63	5·42	4·95	4·79	4·22	4·25
1942	3·59	3·46	..	..	..	..	..	..	..	..	..	..
Averages for 1937-42	3·38	3·22	3·41	4·00	4·82	5·51	5·51	5·32	4·88	4·65	4·26	3·95

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 1.—*Monthly mean heights of Sea-Level*—(concld.)

RANGOON

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1916	9·24	9·16	9·29	9·51	10·11	11·10	10·82	11·32	11·70	11·29	10·48	9·62
1917	9·13	9·20	9·00	9·53	9·72	10·44	11·00	11·54	11·44	11·42	10·72	9·98
1918	9·63	9·31	9·20	9·43	10·27	11·04	11·24	11·66	11·98	10·95	10·11	9·77
1919	9·23	8·99	9·27	9·62	10·12	11·10	11·21	11·69	11·12	10·85	10·75	9·84
1920	9·52	9·27	9·27	9·74	10·59	10·36	11·36	11·42	11·51	10·93	9·94	9·87
					Results not computed							
1937	8·18	8·97	9·08	9·34	9·88	10·95	10·80	11·48	11·45	10·76	9·85	9·62
1938	8·98	8·91	9·24	9·46	10·20	11·13	11·61	11·56	11·45	11·17	10·58	9·34
1939	9·28	9·21	9·13	9·40	10·17	10·73	11·59	12·42	11·69	11·39	10·42	9·36
1940	8·85	8·89	8·99	9·56	10·16	10·66	11·34	11·56	11·30	10·78	10·25	9·53
1941	8·90	8·85	9·15	9·49	10·14	11·03	11·39	11·76	11·39	11·15	9·98	9·71
					Data not available							
1947	8·39	8·52	8·94	9·41	9·88	11·08	11·94	11·98	11·69	11·23	10·22	8·73
1948	8·38	8·55	8·85	9·36	10·15	10·89	11·45	12·50	11·65	10·91	9·89	8·35
Averages for 1916-20 (5 yrs.)	9·35	9·19	9·21	9·57	10·16	10·81	11·13	11·53	11·55	11·09	10·40	9·82

PORT BLAIR

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1916	4·70	4·64	4·58	4·74	4·83	5·07	5·11	5·06	5·01	5·05	5·09	4·90
1917	4·63	4·50	4·50	4·75	4·87	4·83	4·88	4·90	4·99	5·06	5·05	5·05
1918	4·96	4·76	4·76	4·59	4·72	5·01	5·07	4·96	4·87	4·98	5·00	5·10
1919	4·86	4·62	4·52	4·52	4·84	4·98	5·09	4·98	4·89	4·80	5·09	5·03
1920	4·83	4·64	4·64	4·76	5·02	5·09	5·12	5·04	4·99	4·81	4·86	4·83
Average for 1916-20	4·80	4·63	4·60	4·67	4·86	5·00	5·05	4·99	4·95	4·95	5·02	4·98

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*

Year \ Port	Suez	Perim	Aden	Maskat	Basrah	Bushire	Karāchi
1868	..	..	..	..	..	..	7·149
1869	..	..	..	..	..	..	7·291
1870	..	..	..	..	..	..	7·264
1871	..	..	..	..	..	..	7·107
1872	..	..	..	..	..	..	7·051
1873	..	..	..	..	..	..	7·079
1874	..	..	..	..	..	..	7·152
1875	..	..	..	..	..	..	7·153
1876	..	..	..	..	..	..	7·134
1877	..	..	..	..	..	..	7·207
1878	..	..	..	..	..	..	7·331
1879	..	..	..	..	..	..	7 308
1880	..	..	5·755	..	..	..	7·267
1881	..	..	5·829	..	..	..	7·179
1882	..	..	5·751	..	..	..	7·060
1883	..	..	5·789	..	..	..	7·192
1884	..	..	5·842	..	..	..	7·198
1885	..	..	5·879	..	..	..	7·206
1886	..	..	5·906	..	..	..	7·225
1887	..	..	5·814	..	..	..	7·152
1888	..	..	5·869	..	..	..	7·133
1889	..	..	5·832	..	..	..	7·155
1890	..	..	5·808	..	..	..	7·143
1891	..	..	5·836	..	..	..	7·114
1892	..	..	5·837	..	..	4·878	7·243
1893	..	..	5·806	7·694	..	..	7·203
1894	..	..	5·827	7·693	..	4·769	7·217
1895	..	..	5·845	7·639	..	4·695	7·191
1896	..	..	5·837	7·704	..	4·652	7·190
1897	4·338	..	5·933	7·699	..	4·710	7·214
1898	4·360	5·396	5·920	..	..	4·688	7·242
1899	4·392	5·361	5·880	..	..	4·621	7·192
1900	4·402	5·324	5·785	..	..	4·620	7·065
1901	4·400	5·407	5·837	..	..	..	7·151
1902	4·361	5·443	5·990	..	..	..	7·306
1903	4·190	..	5·964	..	..	..	7·282
1904	..	..	5·872	..	..	..	7·210
1905	..	..	5·855	..	..	..	7·120
1906	..	..	5·813	..	..	..	7·224
1907	..	..	5·858	..	..	..	7·328
1908	..	..	5·820	..	..	..	7·178
1909	..	..	5·790	..	..	..	7·163

(*Continued*)

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Suez	Perim	Aden	Maskat	Basrah	Bushire	Karāchi
1910	..	..	5·336	..	..	..	7·233
1911	..	..	5·768	..	..	..	7·223
1912	..	..	5·873	..	..	..	7·312
1913	..	..	5·860	..	..	..	7·243
1914	..	..	5·833	..	..	..	7·318
1915	..	..	5·951	..	..	..	7·318
1916	..	..	5·903	..	6·905	..	7·377
1917	..	..	5·793	..	6·117	..	7·374
1918	..	..	5·852	..	6·479	..	7·340
1919	..	..	5·839	..	7·230	..	7·248
1920	..	..	5·871	..	6·540	..	7·377
1921	..	..	5·839	..	6·383	..	..
1922	..	..	5·841	..	6·439	..	..
1923	..	..	5·834	..	6·085	..	..
1924	..	..	5·815	..	5·853	..	..
1925	..	..	5·854	..	..	..	..
1926	..	..	5·858	..	..	..	..
1927	..	..	5·838	..	..	..	..
1928	..	..	5·816	..	..	..	..
1929	..	..	5·783	..	..	..	..
1930	..	..	5·800	..	..	..	..
1931	..	..	5·872	..	..	..	..
1932	..	..	5·840	..	..	..	..
1933	..	..	5·884	..	..	..	..
1934	..	..	..	..	..	..	..
1935	..	..	..	..	..	..	..
1936	..	..	..	..	..	..	..
1937	..	..	5·97	..	..	..	7·47
1938	..	..	..	..	..	..	7·45
1939	..	..	..	..	..	..	7·36
1940	..	..	6·05	..	..	..	7·43
1941	..	..	6·10	..	..	..	7·46
1942	..	..	6·09	..	..	..	7·42
1943	..	..	6·00	..	..	..	7·26
1944	..	..	..	..	..	..	7·28
1945	..	..	..	..	..	..	7·34
1946	..	..	5·96	..	..	..	7·36
1947	..	..	6·08	..	..	..	..
1948	..	..	6·14	..	..	..	..

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Year \ Port	Hanstal	Navinar	Navlakhi	Port Okha	Porbandar	Port Albert Victor	Bhāvnagar
1868	..	..	..	..	..	..	..
1869	..	..	..	..	..	..	..
1870	..	..	..	..	..	..	..
1871	..	..	..	..	..	..	..
1872	..	..	..	..	..	..	..
1873	..	..	..	..	..	..	..
1874	16·332	15·441	..	9·650	..	..	..
1875	..	..	..	..	..	..	..
1876	..	..	..	..	..	..	..
1877	..	..	..	..	..	..	..
1878	..	..	..	..	..	..	..
1879	..	..	..	..	..	..	..
1880	..	..	..	..	..	..	..
1881	..	..	..	..	..	13·872	..
1882	..	..	..	..	..	..	..
1883	..	..	..	..	..	..	..
1884	..	..	..	..	..	..	..
1885	..	..	..	..	..	..	..
1886	..	..	..	..	..	..	..
1887	..	..	..	..	..	..	..
1888	..	..	..	..	..	..	..
1889	..	..	..	..	..	..	22·703
1890	..	..	..	..	..	..	22·742
1891	..	..	..	..	..	..	22·592
1892	..	..	..	..	..	..	22·699
1893	..	..	..	..	6·129	..	22·550
1894	..	..	..	..	6·461	..	..
1895	..	..	..	..	..	..	..
1896	..	..	..	..	..	..	..
1897	..	..	..	..	..	..	..
1898	..	..	..	..	7.704	..	..
1899	..	..	..	..	..	..	..
1900	..	..	..	..	7·342	9·660	..
1901	..	..	..	..	7·412	9·748	..
1902	..	..	..	..	..	9·858	..
1903	..	..	..	..	..	9·871	..
1904	..	..	..	..	..	..	..
1905	..	..	..	9·598	..	..	..
1906	..	..	..	..	..	..	..
1907	..	..	..	..	..	..	..
1908	..	..	..	..	..	..	..
1909	..	..	..	..	..	..	..

(Continued)

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Hanstal	Navinar	Naviakhi	Port Okha	Por-bandar	Port Albert Victor	Bhāv-nagar
1910	..	..	..	..	..	..	..
1911	..	..	..	..	..	..	..
1912	..	..	..	..	..	..	..
1913	..	..	..	..	..	..	..
1914	..	..	..	..	..	..	..
1915	..	..	..	..	..	..	..
1916	..	..	..	..	..	..	..
1917	..	..	..	..	..	..	..
1918	..	..	..	..	..	..	..
1919	..	..	..	..	..	..	..
1920	..	..	..	..	..	..	..
1921	..	..	..	..	..	..	..
1922	..	..	..	..	..	..	..
1923	..	..	..	..	..	..	..
1924	..	..	..	..	..	..	..
1925	..	..	..	..	..	..	..
1926	..	..	..	..	..	..	..
1927	..	..	..	..	..	..	..
1928	..	..	..	..	..	..	..
1929	..	..	..	..	..	..	..
1930	..	..	..	..	..	..	..
1931	..	..	14·109	..	..	..	..
1932	..	..	..	..	..	..	..
1933	..	..	..	..	..	..	..
1934	..	..	..	..	..	..	..
1935	..	..	..	..	..	..	..
1936	..	..	..	..	..	..	..
1937	..	..	..	..	..	..	19·81
1938	..	..	..	..	..	..	19·72
1939	..	..	..	..	..	..	19·66
1940	..	..	13·81	..	..	..	19·70
1941	..	..	..	..	..	..	19·79
1942	..	..	..	..	..	..	19·59
1943	..	..	..	..	..	..	19·78
1944	..	..	..	..	..	..	20·48
1945	..	..	..	..	..	..	20·27
1946	..	..	..	..	..	..	20·16
1947	..	..	..	..	..	..	20·49
1948	..	..	..	..	..	..	19·88

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Prince's Dock (Bombay)	Bombay (Apollo Bandar)	Mormugao	Kārwār	Beypore	Cochin	Tuticorin	Minicoy
1868	..	..	..	..	..	..	..	..
1869	..	..	..	..	..	..	..	..
1870	..	..	..	..	..	..	..	..
1871	..	..	..	..	..	..	..	..
1872	..	..	..	..	..	..	..	..
1873	..	..	..	..	..	..	..	..
1874	..	..	..	..	..	..	..	..
1875	..	..	..	..	..	..	..	..
1876	..	..	..	..	..	..	..	..
1877	..	..	..	..	..	..	..	..
1878	..	10·267	..	5·650	5·385	..	..	..
1879	..	10·173	..	5·541	5·392	..	..	..
1880	..	10·183	..	5·564	5·412	..	..	..
1881	..	10·254	..	5·515	5·412	..	..	..
1882	..	10·198	..	5·492	5·395	..	..	..
1883	..	10·253	..	..	5·301	..	..	..
1884	..	10·251	5·512	..	..	..	..	..
1885	..	10·309	5·577	..	..	..	..	..
1886	..	10·266	5·573	..	..	2·422	..	..
1887	..	10·204	5·486	..	..	2·359	..	..
1888	8·306	10·250	5·451	..	..	2·307	2·091	..
1889	8·285	10·205	..	..	..	2·421	2·186	..
1890	8·329	10·242	..	..	..	2·345	2·149	..
1891	8·226	10·154	..	..	..	2·331	2·074	5·174
1892	8·386	10·282	..	..	..	..	..	5·269
1893	8·253	10·213	..	..	..	..	..	5·247
1894	8·247	10·235	..	..	..	..	..	5·200
1895	8·274	10·196	..	..	..	..	..	5·192
1896	8·280	10·236	..	..	..	..	..	..
1897	8·262	10·253	..	..	..	..	..	..
1898	8·298	10·337	..	..	..	..	..	..
1899	8·211	10·196	..	..	..	..	..	..
1900	8·065	10·168	..	..	..	..	..	..
1901	8·239	10·228	..	..	..	..	..	..
1902	8·382	10·312	..	..	..	..	..	..
1903	8·290	10·316	..	..	..	..	..	..
1904	8·177	10·181	..	..	..	..	..	..
1905	7·981	10·069	..	..	..	..	..	..
1906	7·989	10·137	..	..	..	..	..	..
1907	8·247	10·183	..	..	..	..	..	..
1908	8·115	10·148	..	..	..	..	..	..
1909	8·119	10·172	..	..	..	..	..	..

(*Continued*)

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Prince's Dock (Bombay)	Bombay (Apollo Bandar)	Mormugao	Kārwār	Beypore	Cochin	Tuticorin	Minicoy
1910	8·201	10·204	..	..	..	..	..	..
1911	8·198	10·182	..	..	..	..	..	..
1912	8·300	10·302	..	..	..	..	..	..
1913	8·221	10·189	..	..	..	..	..	..
1914	8·318	10·253	..	..	..	..	..	..
1915	8·283	10·256	..	..	..	..	..	..
1916	8·404	10·347	..	..	..	..	..	..
1917	8·374	10·326	..	..	..	..	..	..
1918	8·302	10·286	..	..	..	..	..	..
1919	8·357	10·140	..	..	..	..	..	..
1920	8·271	10·278	..	..	..	..	..	..
1921	..	10·304	..	..	..	..	..	..
1922	..	10·246	..	..	..	..	..	..
1923	..	10·134	..	..	..	..	..	..
1924	..	10·262	..	..	..	..	..	..
1925	..	10·236	..	..	..	..	..	..
1926	..	10·275	..	..	..	..	..	..
1927	..	10·222	..	..	..	..	..	..
1928	..	10·201	..	..	..	..	..	..
1929	..	10·340	..	..	..	..	..	..
1930	..	10·298	..	..	..	..	..	..
1931	..	10·44	..	..	..	..	..	..
1932	..	10·42	..	..	..	..	..	..
1933	..	10·50	..	..	..	..	..	..
1934	..	10·46	..	..	..	..	..	..
1935	..	10·33	..	..	..	..	..	..
1936	..	10·34	..	..	..	..	..	..
1937	..	8·49	..	..	..	..	..	..
1938	..	8·52	..	..	..	..	..	..
1939	..	8·42	..	..	..	..	..	..
1940	..	8·52	..	..	..	..	..	..
1941	..	8·44	..	..	..	..	..	..
1942	..	8·44	..	..	..	..	..	..
1943	..	8·51	..	..	..	..	..	..
1944	..	8·50	..	..	..	..	..	..
1945	..	8·42	..	..	..	..	..	..
1946	..	8·49	..	..	..	..	..	..
1947	..	8·42	..	..	..	..	..	..
1948	..	8·54	..	..	..	..	..	..

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Pamban Pass	Colombo	Galle	Trinco-malee	Nega-patam	Madras	Cocā-nada	Vizaga-patam
1868	..	..	..	..	..	..	..	..
1869	..	..	..	..	..	..	..	..
1870	..	..	..	..	..	..	..	..
1871	..	..	..	..	..	..	..	..
1872	..	..	..	..	..	..	..	..
1873	..	..	..	..	..	..	..	..
1874	..	..	..	..	..	..	..	..
1875	..	..	..	..	..	..	..	..
1876	..	..	..	..	..	..	..	..
1877	..	..	..	..	..	..	..	..
1878	2·666	..	..	..	..	..	..	..
1879	2·707	..	..	..	..	..	..	4·991
1880	2·759	..	..	..	..	2·251	..	4·917
1881	2·705	..	..	..	1·996	2·209	..	4·809
1882	..	..	..	..	2·048	2·179	..	4·812
1883	..	..	..	..	..	2·180	..	4·813
1884	..	2·208	2·656	..	..	2·134	..	4·630
1885	..	2·261	2·700	..	1·811	2·051	..	..
1886	..	2·304	2·679	..	2·048	2·320	5·488	..
1887	..	2·199	2·606	..	2·047	2·266	5·324	..
1888	..	2·112	2·570	..	..	2·133	5·154	..
1889	..	2·216	2·685	..	..	2·353	5·413	..
1890	..	..	..	1·842	..	..	5·308	..
1891	..	..	..	1·826	..	..	..	..
1892	..	..	..	2·043	..	..	..	..
1893	..	..	..	1·987	..	..	..	..
1894	..	..	..	1·962	..	..	..	..
1895	..	..	..	1·928	..	2·175	..	..
1896	..	..	..	..	..	1·978	..	..
1897	..	..	..	..	..	2·279	..	..
1898	..	..	..	..	..	2·300	..	..
1899	..	..	..	..	..	2·372	..	..
1900	..	..	..	..	..	2·168	..	..
1901	..	..	..	..	..	2·282	..	..
1902	..	..	..	..	..	2·094	..	..
1903	..	..	..	..	..	2·334	..	..
1904	..	..	..	..	..	2·304	..	..
1905	..	..	..	..	..	2·338	..	..
1906	..	..	..	..	..	2·446	..	..
1907	..	..	..	..	..	2·294	..	..
1908	..	..	..	..	..	2·144	..	..
1909	..	..	..	..	..	2·354	..	..

(*Continued*)

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Pamban Pass	Colombo	Galle	Trinco-malee	Nega-patam	Madras	Cocā-nada	Vizaga-patam
1910	..	..	..	..	..	2·412	..	..
1911	..	..	..	..	..	2·296	..	..
1912	..	..	..	..	..	2·336	..	..
1913	..	..	..	..	..	2·362	..	..
1914	..	..	..	..	..	2·213	..	..
1915	..	..	..	..	..	2·329	..	..
1916	..	..	..	..	..	2·402	..	..
1917	..	..	..	..	..	2·361	..	..
1918	..	..	..	..	..	2·221	..	..
1919	..	..	..	..	..	2·304	..	..
1920	..	..	..	..	..	2·318	..	..
1921	..	..	..	..	..	..	..	..
1922	..	..	..	..	..	..	..	..
1923	..	..	..	..	..	..	..	..
1924	..	..	..	..	..	..	..	..
1925	..	..	..	..	..	..	..	..
1926	..	..	..	..	..	..	..	..
1927	..	..	..	..	..	..	..	..
1928	..	..	..	..	..	..	..	..
1929	..	..	..	..	..	..	..	..
1930	..	..	..	..	..	..	..	..
1931	..	..	..	..	..	..	..	..
1932	..	..	..	..	..	..	..	..
1933	..	..	..	..	..	..	..	..
1934	..	1·29	..	..	..	..	..	..
1935	..	1·22	..	..	..	..	..	..
1936	..	..	..	..	..	..	..	..
1937	..	..	..	..	..	..	..	2·56
1938	..	..	..	..	..	..	..	2·64
1939	..	..	..	..	..	..	..	2·57
1940	..	..	..	..	..	..	..	2·48
1941	..	..	..	..	..	..	..	2·51
1942	..	..	..	..	..	..	..	2·56
1943	..	..	..	..	..	..	..	2·69
1944	..	..	..	..	..	..	..	2·44
1945	..	..	..	..	..	..	..	2·63
1946	..	..	..	..	..	..	..	..
1947	..	..	..	..	..	..	..	2·60
1948	..	..	..	..	..	..	..	2·70

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Year \ Port	Chānd-bāli	Shortt Island	False Point	Dublat (Saugor Island)	Dia-mond Harbour	Kidder-pore	Chitta-gong
1868	..	..	..	..	..	..	..
1869	..	..	..	..	..	..	..
1870	..	..	..	..	..	..	..
1871	..	..	..	..	..	..	..
1872	..	..	..	..	..	..	..
1873	..	..	..	..	..	..	..
1874	..	..	..	..	..	..	..
1875	..	..	..	..	..	..	..
1876	..	..	..	..	..	..	..
1877	..	..	..	..	..	..	..
1878	..	..	..	..	..	..	..
1879	..	..	..	..	..	..	..
1880	..	..	..	..	..	..	..
1881	..	..	7·552	9·565	8·976	..	..
1882	..	..	7·597	9·670	9·011	10·719	..
1883	..	..	7·593	9·588	8·999	10·573	..
1884	..	..	7·492	9·550	8·897	10·669	..
1885	..	..	..	9·434	8·804	10·920	..
1886	..	..	..	..	..	11·359	8·251
1887	..	..	..	..	..	11·166	7·945
1888	..	..	..	..	..	10·836	7·923
1889	..	..	..	..	..	11·164	8·086
1890	..	..	..	..	..	11·485	7·977
1891	..	..	..	..	..	10·622	..
1892	..	..	..	..	..	10·848	..
1893	..	..	..	..	..	11·301	..
1894	..	..	..	..	..	11·383	..
1895	..	..	..	..	..	10·476	..
1896	..	..	..	..	..	10·123	..
1897	..	..	..	..	..	10·535	..
1898	..	..	..	..	..	10·858	..
1899	..	..	..	..	..	10·660	..
1900	..	..	..	..	..	10·604	..
1901	..	..	..	..	..	10·358	..
1902	..	..	..	..	..	10·398	..
1903	..	..	..	..	..	10·711	..
1904	..	..	..	..	..	10·830	..
1905	..	..	..	..	..	10·593	..
1906	..	..	..	..	..	10·722	..
1907	..	..	..	..	..	10·358	..
1908	..	..	..	..	..	10·397	..
1909	..	..	..	..	..	10·770	..

(*Continued*)

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(contd.)

Port / Year	Chāndbāli	Shortt Island	False Point	Dublat† (Saugor Island)	Diamond Harbour	Kidderpore	Chittagong
1910	..	..	..	..	..	10·895	..
1911	..	..	..	..	..	10·781	
1912	..	..	..	..	..	10·314	..
1913	..	..	..	..	..	10·495	..
1914	..	..	..	..	..	10·313	..
1915	..	..	..	..	..	10·453	..
1916	..	..	..	..	..	10·804	..
1917	..	..	..	..	..	10·807	..
1918	..	..	..	..	..	10·318	..
1919	..	..	..	..	..	10·382	..
1920	..	..	..	..	..	10·169	..
1921	..	..	..	..	..	10·10	..
1922	..	..	..	..	..	10·66	..
1923	..	..	..	..	..	9·85	..
1924	..	..	..	..	..	10·39	..
1925	..	..	..	..	..	10·00	..
1926	..	..	..	..	..	9·98	..
1927	..	..	..	..	..	..	..
1928	..	..	..	..	..	..	..
1929	..	..	..	..	..	10·14	..
1930	..	..	..	..	..	10·363* 10·08	.. ..
1931	..	..	..	..	..	10·23	..
1932	5·304	5·762	..	..	..	9·73	..
1933	..	..	..	..	..	10·11	..
1934	..	..	..	..	..	9·84	..
1935	..	..	..	..	..	9·53	..
1936	..	..	..	..	..	10·21	..
1937	..	..	..	10·11	..	10·09	6·74
1938	..	..	..	10·10	..	10·46	7·00
1939	..	..	..	10·07	..	10·654* 10·30	6·83
1940	..	..	..	9·95	..	9·75	6·81
1941	..	..	..	9·91	..	10·09	7·01
1942	..	..	..	9·98	..	10·45	..
1943	..	..	..	..	..	10·37	..
1944	..	..	..	..	..	9·84	6·43
1945	..	..	..	..	..	9·97	6·75
1946	..	..	..	..	..	10·11	6·81
1947	..	..	..	..	..	10·29	6·99
1948	..	..	..	..	..	10·27 10·356*	..

* Derived rigorously from hourly heights.

† Values on Saugor Island from 1937 onwards refer to Saugor Point, which is about 5 miles west of Dublat.

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-level*—(contd.)

Port / Year	Akyab	Diamond Island	Bassein	Elephant Point	Rangoon	Amherst	Moulmein	Mergui	Port Blair
1868	..	..	..	..	..	..	..	..	..
1869	..	..	..	..	..	..	..	..	..
1870	..	..	..	..	..	..	..	..	..
1871	..	..	..	..	..	..	..	..	..
1872	..	..	..	..	..	..	..	..	..
1873	..	..	..	..	..	..	..	..	..
1874	..	..	..	..	..	..	..	..	..
1875	..	..	..	..	..	..	..	..	..
1876	..	..	..	..	..	..	..	..	..
1877	..	..	..	..	..	..	..	..	..
1878	..	..	..	..	..	..	..	..	..
1879	..	..	..	..	..	..	..	..	..
1880	..	..	..	16·554	10·508	13·591	8·453	..	4·792
1881	..	..	..	..	10·414	13·974	8·659	..	4·718
1882	..	..	..	..	10·387	13·701	8·658	..	4·710
1883	..	..	..	..	10·359	13·757	8·737	..	4·726
1884	..	..	..	12·418	10·173	13·588	8·146	..	4·689
1885	..	..	..	11·745	10·077	13·311	8·388	..	4·612
1886	..	..	..	11·997	10·407	..	..	..	4·506
1887	7·486	..	..	11·982	10·194	..	..	..	4·709
1888	7·430	..	..	11·903	10·161	..	..	..	4·625
1889	7·684	..	..	..	10·299	..	..	13·084	4·586
1890	7·535	..	..	..	10·374	..	..	12·983	4·605
1891	7·452	..	..	..	9·991	..	..	12·902	4·606
1892	..	..	..	..	10·264	..	..	12·999	4·811
1893	..	..	..	..	10·217	..	..	12·984	4·677
1894	..	..	..	..	10·152	..	..	..	4·742
1895	..	7·141	..	..	10·034	..	..	..	4·658
1896	..	7·133	..	..	10·070	..	..	..	4·753
1897	..	7·326	..	..	10·198	..	..	..	4·800
1898	..	7·304	..	..	10·212	..	..	..	4·795
1899	..	7·311	..	..	10·320	..	..	..	4·779
1900	..	..	..	..	10·155	..	..	..	4·752
1901	..	..	..	..	10·253	..	..	..	4·784
1902	..	..	9·013	..	10·031	..	..	..	4·717
1903	..	..	8·806	..	10·259	..	..	..	4·864
1904	..	..	..	..	10·275	..	..	..	4·787
1905	..	..	..	..	10·209	..	..	..	4·703
1906	..	..	..	..	10·285	..	..	..	4·782
1907	..	..	..	..	10·241	..	..	..	4·833
1908	..	..	..	..	10·130	..	..	..	4·709
1909	..	..	..	..	10·303	..	8·603	..	4·868

(*Continued*)

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 2.—*Annual Mean Heights of Sea-Level*—(concld.)

Port / Year	Akyab	Diamond Island	Bassein	Ele-phant Point	Ran-goon	Amherst	Moul-mein	Mergui	Port Blair
1910	..	..	..	..	10·378	..	8·623	..	4·877
1911	..	..	..	..	10·348	..	8·589	..	4·805
1912	..	..	..	..	10·218	..	8·277	..	4·828
1913	..	..	..	..	10·192	..	8·410	..	4·823
1914	..	..	..	..	10·208	..	8·392	..	4·815
1915	..	..	..	..	10·410	..	8·449	..	4·933
1916	..	..	..	..	10·304	..	8·232	..	4·895
1917	..	..	..	..	10·306	..	8·426	..	4·836
1918	..	..	..	..	10·387	..	8·921	..	4·901
1919	..	..	..	..	10·324	..	8·702	..	4·855
1920	..	..	..	..	10·320	..	8·636	..	4·887
1921	..	..	..	..	..	..	..	..	..
1922	..	..	..	..	..	..	..	..	..
1923	..	..	..	..	..	..	..	..	..
1924	..	..	8·330	..	..	..	..	..	..
1925	..	..	8·162	..	..	..	..	..	..
1926	..	..	8·076	..	..	..	..	..	..
1927	..	..	8.309	..	..	..	..	..	..
1928	..	..	8·109	..	..	..	..	..	..
1929	..	..	..	..	..	..	..	..	..
1930	..	..	..	..	..	..	..	..	..
1931	..	..	..	..	..	..	..	..	..
1932	..	..	..	..	..	..	..	..	..
1933	..	..	..	..	..	..	..	..	..
1934	..	..	..	..	..	..	..	..	..
1935	..	..	..	..	..	..	..	..	..
1936	..	..	..	..	..	..	..	..	..
1937	4·29	..	..	..	10·03	..	..	..	..
1938	4·51	..	..	..	10·30	..	..	..	..
1939	4·43	..	..	..	10·40	..	..	..	..
1940	4·28	..	..	..	10·16	..	..	..	..
1941	4·49	..	..	..	10·24	..	..	..	..
1942	..	..	..	..	..	..	..	..	..
1943	..	..	..	..	..	..	..	..	..
1944	..	..	..	..	..	..	..	..	..
1945	..	..	..	..	..	..	..	..	..
1946	..	..	..	..	..	..	..	..	..
1947	..	..	..	..	10·17	..	..	..	..
1948	..	..	..	..	10·08	..	..	..	..

NOTE.—For details regarding zero of heights, method of reduction, etc., see Table 3.

TABLE 3.—*Synopsis of tidal data available for*

Station	M.S.L. Data available				M.S.L. results already computed (vide Tables 1 and 2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Suez ..	1897–1903	..	..	(*a*) 1898–1903	..	1897–1903	..
Perim ..	1898–1902	..	..	(*a*) 1900–02	..	1898–1902	..
Aden ..	1879–1920	1921–48	1921–37	(*a*) 1879–1948	1916–33	1880–1915	(*a*) 1937 (*a*) 1940–43 (*a*) 1946–48
Maskat ..	1893–97	..	..	(*a*) 1895–98	..	1893–97	..
Basrah ..	1916–24	..	..	(*a*) 1918–32	..	1916–24	..
Bushire ..	1892–93 1894–1900	.. ..	.. ..	(*a*) 1896–1901	.. ..	1892–93 1894–1900	.. ..
Karāchi ..	1868–1920	1921–48	1922–37	(*a*) 1883–1948	1916–20	1868–1915	(*a*) 1937–48
Hanstal ..	1874–75	..	..	..	..	1874–75	..
Navinar ..	1874–75	..	..	..	..	1874–75	..
Navlakhi ..	1931–32	..	..	(*a*) 1931–32 (*a*) 1940–41	..	1931–32	(*a*) 1931–32 (*a*) 1940–41

(1) Hourly heights from Harmonic Analysis.
(2) Hourly heights from T.G. diagram.
(3) Hourly heights from observatory reports.
(4) High and Low water readings (*a*) day and night (*b*) day only.
* Below local M.S.L.

M.S.L. computation, and of results computed—(contd.)

Zero of heights in Tables 1 and 2				B.M. of reference (Description)
for period	below Indian M.S.L.	below 'Datum of Soundings	below B.M. of reference	
1897–1903	4·35*	0·62	10·96	G.T.S. □ B.M.B. embedded in the SE. wall of the dry dock at Port Ibrahim.
1898–1902	5·39*	0·91	10·63	G.T.S. □ B.M. embedded in an angle of the Blacksmith's shop.
1879–1933 1937–48	5·84* 4·25*	1·59 Nil	12·99 11·40	G.T.S. □ B.M. in the verandah of the Port Engineer's Office.
1893–97	7·69*	2·92	25·50	G.T.S. □ B.M. A. embedded in the south verandah of the British Residency.
1916–24	5·00†	Nil	15·02	B.M. is an iron band fixed to the NE. stanchion of the foundry of the Inland Water Transport Dockyard.
1892–93 } 1894–1900 }	4·70*	1·82	40·32	O.B. black stone let into the seaward coping of the Cable House.
1868–1920 1937–48	7·21 5·21	2·00 Nil	16·14 14·14	G.T.S. B.M. A. □ A.D. 1880 110 yards SW. of the Tidal observatory.
1874–75	16·33*	Not known	26·03	G.T.S. □ B.M. A 8 feet E. of a specially built pillar about a quarter of a mile NNE. of a flagstaff called Mustasa-Pir ka-Bāuta.
1874–75	15·44*	..	25·37	G.T.S. □ B.M. C 20 chains SW. of the lighthouse.
1931–32 } 1940–41 }	14·11*	0·50	27·00	Marine Survey B.M. ↑ cut on the pier under the top step.

(Continued)

(5) From hourly heights for 365 days (Jan.–Dec.) excluding incomplete tidal periods.

(6) From hourly heights for 370 days, obtained in the course of Harmonic Analysis.

(7) From High and Low water readings (*a*) day and night (*b*) day only.

† Below the M.S.L. at Fao.

TABLE 3.—*Synopsis of tidal data available for*

Station	M.S.L. Data available				M.S.L. results already computed (vide Tables 1 and 2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Port Okha ..	1874–75 1904–05	.. ..	.. ..	.. ..	.. ..	1874–75 1904–05	..
Porbandar ..	1893–94 1898–99 1900–01	.. .. ..	.. .. ..	(a) 1897–1901	.. .. ..	1993–94 1898–99 1900–01	
Port Albert Victor ..	1881–82	..	..	..	..	1881–82	..
	1900–03	..	..	(a) 1900–03	..	1900–03	..
Bhāvnagar ..	1889–93	..	..	(a) 1889–93 (b) 1895–1948	..	1889–93	(b) 1937–48
Bombay (Prince's Dock) ..	1888–1920	..	1922	(a) 1890–1921	..	1888–1920	..
Bombay (Apollo Bandar)	1876 1878–1920	.. 1921–48	.. 1921–34	.. (a) 1883–1948	1878–1930	..	(a) 1931–48
Mormugao ..	1884–88	..	..	(a) 1886–88	..	1884–88	..
Karwār ..	1878–83	..	..	(a) 1883	..	1878–82	..
Beypore ..	1878–84	..	..	(a) 1883–85	..	1878–83	..
Cochin ..	1886–92	..	..	(a) 1888–97	..	1886–91	..

(1) Hourly heights from Harmonic Analysis.
(2) Hourly heights from T.G. diagram.
(3) Hourly heights from observatory reports.
(4) High and Low water readings (*a*) day and night (*b*) day only.
* Tho datum of soundings in this case is below the zero of heights.

M.S.L. computation, and of results computed—(contd.)

Zero of heights in Tables 1 and 2				B.M. of reference (Description)
for period	below Indian M.S.L.	below Datum of Soundings	below B.M. of reference	
1874–75 } 1904–05	10·26	2·93	20·08	G.T.S. □ B.M. A 100 feet north of the site of the Tidal observatory.
1893–94	5·89	0·05	21·85	Marine Survey B.M. ↑ cut on the south face of the Sea wall.
1898–99	7·26	1·42	23·22	
1900–01	7·30	1·46	23·26	
1881–82	14·38	8·20	20·94	B.M. cut on the plinth of the lighthouse below the doorway.
1900–03	10·18	4·00	16·74	
1889–93	23·13	2·92	43·35	G.T.S. O B.M. dressed block of stone close to the steam ferry incline.
1937–48	20·21	Nil	40·43	
1888–1920	8·23	—14·00*	28·00	Standard B.M. at the P.W.D. Secretariat.
1878–1936	10·23	2·00	29·96	Standard B.M. at the P.W.D. Secretariat.
1937–48	8·23	Nil	27·96	
1884–88	5·52	2·00	17·82	G.T.S. B.□M. A.D. 1884 embedded in masonry, west of the embrasure of the old Fort.
1878–82	5·56	1·86	17·33	G.T.S. □ B.M. embedded in a block of masonry close to the Traveller's Bungalow.
1878–83	5·38	2·50	19·79	G.T.S. □ B.M. A 100 feet east of the Custom House front door.
1886–91	2·36	0·45	8·93	G.T.S. □ A B.M. in the verandah of the Harbour Master's Office.

(Continued)

(5) From hourly heights for 365 days (Jan.–Dec.) excluding incomplete tidal period.
(6) From hourly heights for 370 days, obtained in the course of Harmonic Analysis.
(7) From High and Low water readings (*a*) day and night (*b*) day only.

TABLE 3.—*Synopsis of tidal data available for*

Station	M.S.L. Data available				M.S.L. results already computed (vide Tables 1 and 2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Tuticorin ..	1888–93	..	..	1890–1900	..	1888–91	..
Minicoy	1891–95	..	..	(a) 1893–95	..	1891–95	..
Pāmban Pass	1878–82	..	..	..	..	1878–81	..
Colombo ..	1884–90	..	..	(a) 1886–90 (a) 1897–98	..	1884–89	..
				(a) 1929–35	..	..	(a) 1934–35
Galle ..	1884–90	..	..	(a) 1885–90	..	1884–89	..
Trincomalee	1890–95	..	..	(a) 1893–96 (a) 1928–33	..	1890–95	..
Negapatam ..	1881–82	..	..	(a) 1883–88	..	1881–82	..
	1885–88	..	..	..	..	1885–87	
Madras ..	1880–90	1921–33	1922–33	(a) 1883–90	..	1880–89	..
	1895–1920	..	..	(a) 1894–1933	1916–20	1895–1915	..
Cocanada ..	1886–91	..	..	(a) 1888–93	..	1886–90	..
Vizagapatam	1879–85	..	..	(a) 1883–85	..	1879–84	(a) 1937–45
				(a) 1934–48	..	..	(a) 1947–48

(1) Hourly heights from Harmonic Analysis.
(2) Hourly heights from T.G. diagram.
(3) Hourly heights from observatory reports.
(4) High and Low water readings (*a*) day and night (*b*) day only.
* Below local M.S.L.

M.S.L. computation, and of results computed—(contd.)

Zero of heights in Tables 1 and 2				B.M. of reference (Description)
for period	below Indian M.S.L.	below Datum of Soundings	below B.M. of reference	
1888–91	4·70	0·27	8·91	G·T.S. ↑ A.D. 1869 in the verandah of the office of B.I.S.N. Coy. (Mr. Cocque's house).
1891–95	5·22*	2·00	10·05	G.T.S. □ A B.M. 113½ feet east of the north-east corner of the Katcheri.
1878–81	2·71	1·38	10·18	G.T.S. □ B.M. A close to the west wall of the Telegraph Cable House.
1884–89	2·22*	0·98	10·07	G.T.S. □ B.M. situated close under the outer wall of the double flight of steps leading to the Custom House.
1934–35	1·24*	Nil	9·09	
1884–89	2·65*	1·54	7·71	G.T.S. □ B.M. A.D. 1884 embedded in a block of masonry 4 feet outside the fort wall and 9 feet east of the northern gateway.
1890–95	2·12*	0·81	5·90	G.T.S. A.□ B.M. 1890 situated in the wharf of the Naval Dock-yard.
1881–88	1·99	0·88	11·61	G.T.S. O A B.M. flag-stone embedded in the verandah of the Marine office.
1880–89 } 1895–1920 }	2·29	0·35	16·92	G.T.S. O C B.M. cut on the third step on the east side of Lord Cornwalli's fountain.
1886–90	5·26	2·71	11·30	G.T.S. □ A B.M. embedded near the SE. corner of the Marine Office.
1879–84	4·83	2·22	24·63	Standard Bench-mark, marked "GTS/SBM/1910", about 220 yards NE. of the chapel of the Blessed Virgin.
1937–48	2·61	Nil	22·41	

(Continued)

(5) From hourly heights for 365 days (Jan.–Dec.) excluding incomplete tidal period.

(6) From hourly heights for 370 days, obtained in the course of Harmonic Analysis.

(7) From High and Low water readings (*a*) day and night (*b*) day only.

TABLE 3.—*Synopsis of tidal data available for*

Station	M.S.L. Data available				M.S.L. results already computed (vide Tables 1 and 2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Chāndbāli ..	1931–32	..	..	(a) 1933–35	..	1931–32	..
Shortt Island	1931–32	..	..	(a) 1935–36	..	1931–32	..
False Point ..	1881–85	..	..	(a) 1883–85	..	1881–84	..
Dublat (Saugor Island) ..	1881–86	..	..	(a) 1881–86	..	1881–85	(a) 1937–42
Saugor ..	1945–48	..	..	(a) 1933–43 (a) 1945–48			
Diamond Harbour ..	1875–77 1881–86	.. ..	.. ..	(a) 1881–86 ..	.. ..	.. 1881–85	.. ..
Kidderpore (Calcutta) ..	1881–1920	1921–48	1922–37	(a) 1880–85 (a) 1887–88 (a) 1902–48	1929 1938 1948	1882–1920	(a) 1921–48
Chittagong ..	1886–91	..	..	(b) 1887–1910 (b) 1912–41 (b) 1943–47	.. ..	1886–90 ..	(b) 1937–41 (b) 1944–47
Akyab ..	1887–92	..	..	(b) 1888–1910 (b) 1912–42	..	1887–91	(b) 1937–41

(1) Hourly heights from Harmonic Analysis.
(2) Hourly heights from T.G. diagram.
(3) Hourly heights from observatory reports.
(4) High and Low water readings (*a*) day and night (*b*) day only.
* Below local M.S.L.

M.S.L. computation, and of results computed—(contd.)

Zero of heights in Tables 1 and 2				B.M. of reference (Description)
for period	below Indian M.S.L.	below Datum of Soundings	below B.M. of reference	
1931–32	4·15	1·51	19·92	B.M. is at the base of the flagstaff in front of the Port Office.
1931–32	5·76	0·85	24·63	The mark is below the head of a bolt on the north-east corner of the lightmast.
1881–84	7·56	2·50	17·95	Marine Survey B.M. cut on the SW. pile of the Refuge House at Hookey Tollah .
1881–86	9·16	—0·10†	19·45	Top of a rail embedded in a block of masonry and situated about 77 ft. north of the Saugor Semaphore.
1937–43	8·82	—0·44†	19·11	
1881–85	7·76	—1·50†	14·48	G.T.S. B.M. AD 194 embedded in the paddy field about 180 yards north of the embankment along the Hooghly and about 3 furlongs NE. of the new tidal observatory (1948).
1881–1948	7·76	Nil	23·80	H.R.S. B.M. about 300 feet away from the tidal observatory at Garden Reach, near the entrance to the King George's Dock.
1886–90	6·66	1·17	22·71	B.M. A situated near the SE. corner of the Port Office.
1937–48	5·49	Nil	21·54	
1887–91	7·89*	3·36	19·56	G.T.S. B.M. situated in the portico of the Marine Office.
1937–42	4·53*	Nil	16·20	

(Continued)

(5) From Hourly heights for 365 days (Jan.–Dec.) excluding incomplete tidal period.
(6) From hourly heights for 370 days, obtained in the course of Harmonic Analysis.
(7) From High and Low water readings (*a*) day and night (*b*) day only.
† Datum of Soundings in this case is below the zero of heights.

TABLE 3.—*Synopsis of tidal data available for*

Station	M.S.L. Data available				M.S.L. results already computed (vide Tables 1 and 2)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Diamond Island ..	1895–99	..	..	(*a*) 1897–99	..	1895–99	..
Bassein ..	1902–03	..	..	(*a*) 1902–03	..	..	..
	1924–28	..	1924–28	(*a*) 1924–29			
Elephant Point	1880–81	..	..	(*a*) 1880–81	..	1880	..
	1884–88	1927–28	1927–28	(*a*) 1884–88	..	1884–88	
				(*a*) 1927–31			
Rangoon ..	1880–1920	1921–41	1922–42	(*a*) 1880–85	1916–20	1880–1915	(*a*) 1937–41
				(*a*) 1887	..	..	(*b*) 1947–48
				(*a*) 1902–42			
				(*b*) 1947–48			
Amherst ..	1880–86	..	..	(*a*) 1880–86	..	1880–85	..
Moulmein ..	1880–86	1921–24	1922–24	(*a*) 1880–1924	..	1880–85	..
	1909–1920	..	..	..	..	1909–20	
Mergui ..	1889–94	..	..	(*a*) 1889–94	..	1889–93	..
Port Blair ..	1880–1920	1921–25	1922–25	(*a*) 1883–1925	..	1880–1920	..

(1) Hourly heights from Harmonic Analysis.
(2) Hourly heights from T.G. diagram.
(3) Hourly heights from observatory reports.
(4) High and Low water readings (*a*) day and night (*b*) day only.
* Below local M.S.L.

M.S.L. computation, and of results computed—(concld.)

Zero of heights in Tables 1 and 2				B.M. of reference (Description)
for period	below Indian M.S.L.	below Datum of Soundings	below B.M. of reference	
1895–99	7·24*	2·55	24·67	G.T.S. □ A B.M. embedded in masonry at the foot of the flagstaff hill.
1902–03	7·29†	3·62	15·15	G.T.S. O A B.M. embedded in the step leading to the Port and Custom Office.
1924–28	6·15†	2·48	14·01	
1880	16·17†	4·90	30·92	↑ inscribed on an iron plate on top of a block of masonry. Situated on a flat concrete pillar (1947) in a fenced enclosure.
1884–88	11·27†	Nil	26·02	
1880–1948	8·99†	Nil	25·08	Situated below Scotts' B.M., a concrete block one foot square, within a walled enclosure SW. of the Port Commissioner's flagstaff at the bottom of the Lewis Street.
1880–85	13·65*	3·59	38·30	B.M. 36 / 94 H situated at the P.W.D. Inspection Bungalow.
1880–85 } 1909–20 }	5·05†	2·66	26·56	B.M. 22 / 94 H situated in verandah of the Telegraph Office.
1889–93	12·99*	3·85	26·49	A G.T.S. O B.M. embedded in a block of masonry 5 feet from the SE. corner of the Post Office.
1880–1920	4·76*	1·16	13·27	G.T.S. □ C B.M. situated in the compound of the Settlement Club.

(5) From Hourly heights for 365 days (Jan.–Dec.) excluding incomplete tidal period.
(6) From hourly heights for 370 days, obtained in the course of Harmonic Analysis.
(7) From High and Low water readings (*a*) day and night (*b*) day only.
† Below Amherst M.S.L.

TABLE 4 —*9-Yearly M.S.L.*

Port / Period	Aden	Karāchi	Bombay (P.D.)	Bombay (A.B.)	Madras	Port Blair	Kidder-pore	Rangoon
1868–76	..	7·153						
69–77	..	7·160						
1870–78	..	7·164						
71–79	..	7·169						
72–80	..	7·187						
73–81	..	7·201						
74–82	..	7·199						
75–83	..	7·203						
76–84	..	7·208						
77–85	..	7·216						
1878–86	..	7·218	..	10·239				
79–87	..	7·199	..	10·232				
1880–88	5·826	7·179	..	10·241	..	4·676	..	10·298
81–89	5·835	7·167	..	10·243	..	4·653	..	10·275
82–90	5·832	7·163	..	10·242	..	4·641	10·979	10·270
83–91	5·842	7·169	..	10·237	..	4·629	10·968	10·226
84–92	5·847	7·174	..	10·240	..	4·639	10·998	10·216
85–93	5·843	7·175	..	10·236	..	4·637	11·069	10·220
86–94	5·837	7·176	..	10·228	..	4·652	11·120	10·229
87–95	5·830	7·172	..	10·220	..	4·669	11·022	10·187
88–96	5·833	7·177	8·287	10·224	..	4·674	10·906	10·174
89–97	5·840	7·186	8·282	10·224	..	4·693	10·882	10·178
1890–98	5·850	7·195	8·284	10·239	..	4·716	10·848	10·168
91–99	5·858	7·201	8·271	10·234	..	4·736	10·867	10·162
92–1900	5·852	7·195	8·253	10·235	..	4·752	10·865	10·180
93–1901	5·852	7·185	8·237	10·229	..	4·749	10·700	10·179
94–1902	5·874	7·196	8·251	10·240	..	4·753	10·599	10·158
95–1903	5·889	7·204	8·256	10·249	2·220	4·767	10·525	10·170
96–1904	5·891	7·206	8·245	10·247	2·235	4·781	10·564	10·197
97–1905	5·893	7·198	8·212	10·229	2·275	4·776	10·616	10·212
98–1906	5·880	7·199	8·181	10·216	2·293	4·774	10·637	10·222
1899–1907	5·873	7·209	8·176	10·199	2·292	4·778	10·582	10·225
1900–08	5·866	7·207	8·165	10·194	2·267	4·770	10·552	10·204
01–09	5·867	7·218	8·171	10·194	2·288	4·783	10·571	10·221
02–10	5·866	7·227	8·167	10·191	2·302	4·793	10·630	10·235
03–11	5·842	7·218	8·146	10·177	2·325	4·803	10·673	10·270
04–12	5·832	7·221	8·147	10·175	2·325	4·799	10·629	10·265
05–13	5·830	7·225	8·152	10·176	2·331	4·803	10·592	10·256
06–14	5·828	7·247	8·190	10·197	2·317	4·816	10·561	10·256
07–15	5·843	7·257	8·222	10·210	2·304	4·832	10·531	10·270
08–16	5·848	7·263	8·240	10·228	2·316	4·839	10·580	10·277
09–17	5·845	7·285	8·269	10·248	2·341	4·853	10·626	10·296
1910–18	5·852	7·304	8·289	10·261	2·326	4·857	10·576	10·306
11–19	5·852	7·306	8·306	10·253	2·314	4·854	10·519	10·300
12–20	5·864	7·323	8·314	10·264	2·316	4·864	10·451	10·297
13–21	5·860	..	..	10·264				
14–22	5·858	..	..	10·271				
15–23	5·858	..	..	10·257				
16–24	5·843	..	..	10·258				
17–25	5·838	..	..	10·246				
18–26	5·845	..	..	10·240				
19–27	5·843	..	..	10·233				
1920–28	5·841	..	..	10·240				
21–29	5·831	..	..	10·247				
22–30	5·827	..	..	10·246				
23–31	5·830							
24–32	5·831							
1925–33	5·838							

SECTION II.—SUBSIDENCE OF S. BENGAL AS EVIDENCED BY TIDAL AND LEVELLING OPERATIONS

1. General Considerations.—For studies of coastal subsidence, sea-level determinations from systematic tidal observations furnish perhaps the only data of a quantitative nature. A change, in the course of years, in the established relation between Mean Sea-Level and a permanent (stable) bench-mark at a tidal station indicates a relative subsidence or elevation of land with respect to water. To analyse this relative movement*, it is necessary to consider the evidence of the tidal regime at the port. If, for instance, the tidal datum planes (M.T.L., M.H.W., M.L.W., M.H.W.S., etc.) have all risen by the same amount with respect to the reference bench-mark, the tidal range remaining unaffected, the coast can be taken to have subsided by that amount. If, on the other hand, the datum planes have all changed differently, the indication is that the tidal regime has changed and that considerable changes in the sea bed and other hydrographic features have taken place causing such a change. In this case the problem becomes complicated since it would be necessary to investigate whether these hydrographic changes have occurred as a result of any actual subsidence (or emergence) of the coast or as a result of artificial improvements in the harbour like dredging, deepening or widening of the harbour entrance.

It might be mentioned that as between the open coast and inland bodies of water (e.g., tidal rivers), the investigation of coastal subsidence is relatively simple for the former. The reason for this is, that on the open coast, only profound changes in the hydrographic features can bring about changes in the range of the tide, while in inland waters, because of the relatively limited areas and depths involved, small changes in the features are enough to produce large changes in the range. In the former case, therefore, the tidal datum planes generally remain constant for periods covering many years, and any slight subsidence or emergence of the coast is directly reflected by an equivalent change in these datums ; while in the latter case, as for instance in a tidal river, a slight dredging in the channel or a little widening or deepening of the river mouth brings about a large increase in the tidal range and a lowering of the mean water level some distance up stream, thus causing non-uniform changes in the tidal datums and consequent difficulties in analysis.

Data next in importance for such investigations of local upheaval or subsidence of a region, are those provided by repititions of levelling at frequent intervals. Geological and archæological evidences can also be very helpful in considering whether or not a secular movement of land with respect to water has taken place.

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* Such movements are generally assumed to have occurred due to movement of the land rather than of water. Any absolute change in water level can only occur due to world-wide causes like glaciation, deglaciation, etc., and to detect this it is necessary to study tide-gauge observations at a number of open sea ports throughout the world.

2. Areas of Subsidence.—There is a general belief that certain areas in India such as the Kāthiāwār coast, the land near the Rann of Kutch, Calcutta, etc., are in a state of gradual subsidence. In particular, the stability of Calcutta has, since some time past, been the subject of grave concern, and opinions have frequently been expressed that no further buildings should be allowed to be constructed on its alluvial soil, since such constructions would only help the subsidence and ultimately bring about inundation of the city. A study of the gradual movements of soil in this area is thus most important.

3. Tidal Evidence.—Kidderpore (Calcutta) is the only port in S. Bengal for which a long series of continuous tidal observations are available. This data covers the period 1881 to date. Some observations have also been taken for Diamond Harbour and Dublat (Saugor) further down the Hooghly, but these cover only a few years and are, therefore, not of much value for our present discussion.

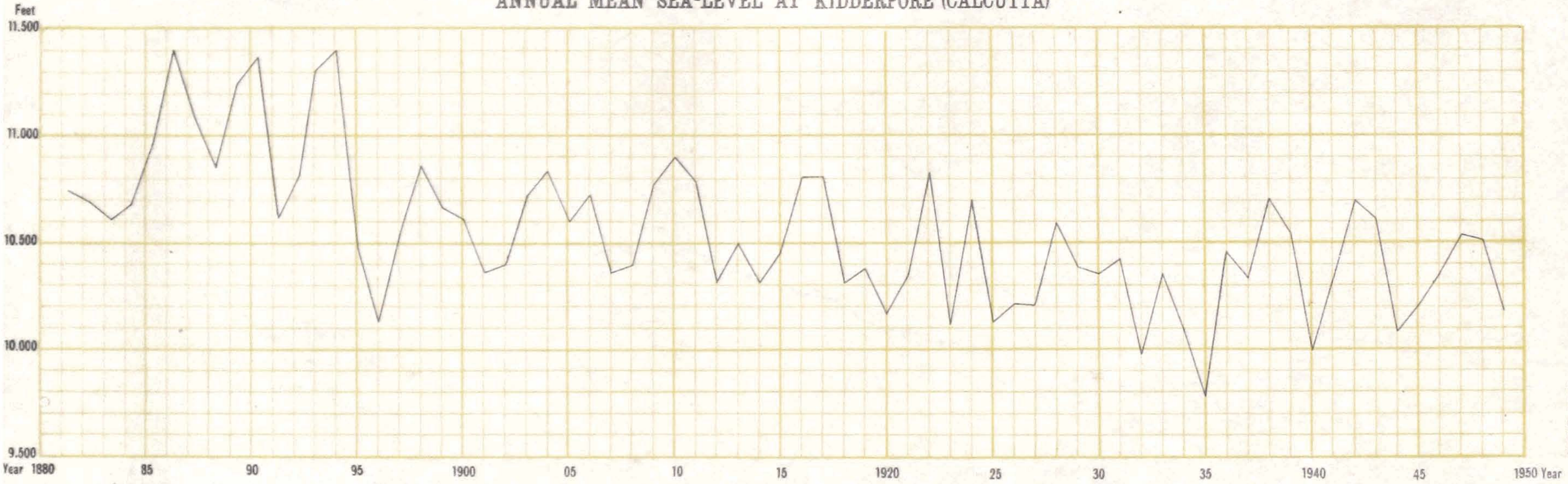
Table 1 gives the yearly values of mean sea-level (strictly speaking, mean river level) at Kidderpore beginning from 1881, and Chart XXXII shows the corresponding graph. The values from 1921 onwards are a little approximate in that they have been derived only from mean tide level values (means of high and low water) by applying a uniform correction of $+0{\cdot}20$ feet. This correction has been arrived at by comparison of M.S.L. and M.T.L. for 5 specimen years between 1900 and 1948 and is unlikely to be grossly in error.

Tables 2 and 3 give the 9-yearly and 19-yearly values computed by the method of moving means, and Chart XXXIII shows the corresponding curves. The full tidal cycle is completed only in 19 years and the 19-yearly means are naturally to be preferred for investigating any changes of level. These indicate that there is a gradual fall of the M.S.L. from about 1890 to about 1932 and thereafter a slight, though not marked, upward trend. The fall in the M.S.L. during the above period of 42 years amounts to a little over half a foot.

This fall in the M.S.L. would appear to indicate a corresponding rise of the land in relation to water, but the port being situated on a river, caution is necessary before forming conclusions. Firstly, it is to be noted that the change in the M.S.L. between 1881 to 1948 has not been gradual and systematic in one direction. There is a rise between 1881 and 1890, then a gradual fall up to about 1932 and thereafter a rise again ; secondly, Kidderpore being a riverain port, the M.S.L. is bound to be affected by variations in the volume of water flowing in the river. Such variations can be brought about by changes in meteorological conditions such as rainfall, melting of snow in the hills, freshets, etc. They can also be due to changes in the hydrographic features of the river, for which there is ample evidence as the paragraphs below will show.

Chart XXXII

ANNUAL MEAN SEA-LEVEL AT KIDDERPORE (CALCUTTA)



Reg. No. 598M/N.C.D.'50 (G. & T. C.)-375

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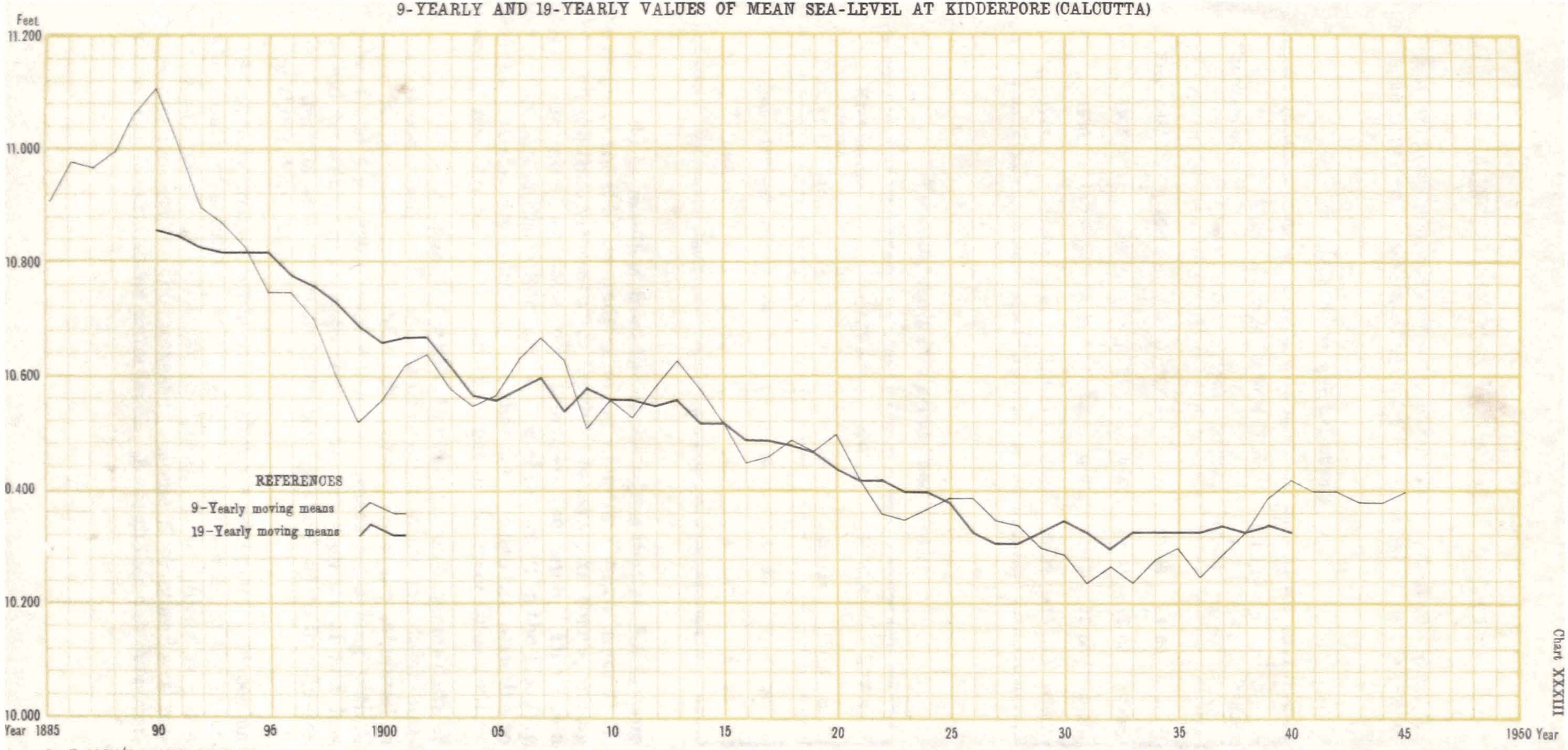
9-YEARLY AND 19-YEARLY VALUES OF MEAN SEA-LEVEL AT KIDDERPORE (CALCUTTA)



Reg. No. 599M/N. C. D. 50 (G. & T. C.)-375

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The various non-harmonic tidal constants of Kidderpore for four specimen years between 1881 and 1948 are tabulated below :—

Non-harmonic Constants

KIDDERPORE	H.W.S. (*feet*)	L.W.S. (*feet*)	H.W.N. (*feet*)	L.W.N. (*feet*)	M.T.L. (*feet*)	Spring Range (*feet*)	Neap Range (*feet*)
Year 1881–82	16·98	5·32	12·15	7·17	10·40	11·66	4·98
„ 1905	17·42	5·40	12·23	6·57	10·40	12·02	5·66
„ 1930	17·19	4·64	11·90	6·75	10·13	12·55	5·15
„ 1947	18·03	4·56	12·07	6·64	10·32	13·47	5·43

Time intervals in Springs and Neaps

KIDDERPORE *minus* DUBLAT (SAUGOR)	H.W.S. h m	L.W.S. h m	H.W.N. h m	L.W.N. h m
Year 1881–82	4 08	6 14	4 17	5 28
„ 1941–42	3 44	6 14	4 12	5 25

It would be manifest from the above tables that at Kidderpore the range of the tide has undergone considerable changes since 1881, although the time interval after Dublat (Saugor) for corresponding tidal occurrences has practically remained the same. There is a distinct change in the volume and shape of the water in the Hooghly and there can hardly be any doubt that this change has been due to dredging and other hydrographic changes in the river since 1881.

That the tidal regime in the river Hooghly has undergone a distinct change is confirmed by the results of mean monthly luni-tidal intervals for Kidderpore and Dublat (Saugor). These are tabulated in Tables 4 and 5 for two specimen years separated by a long period. It would be seen that at both the ports, the high water and low water intervals seem to have increased by about 25 to 30 minutes during the last 66 years.

As already pointed out in para 1 above, a widening or deepening of the mouth of a tidal river brings about a lowering of the mean level of the water some distance upstream. It is difficult to get a precise relation between the increase in volume of water and a corresponding change in the mean water level. A rough idea can, however, be obtained from the simple relation that if the M.S.L. at a given point of the river is lowered by d feet and the range is increased by r feet, the M.H.W., M.S.L. and M.L.W. are lowered by ($d - r/2$), d and ($d + r/2$) feet respectively. In actual practice ($d - r/2$) is negative and so the mean high water is really raised.

In the case of Kidderpore we find from the table of non-harmonic constants above that between 1881 and 1930 the M.H.W. has practically remained constant while the M.L.W. has fallen by about 0·6 feet. We accordingly derive a value of about 0·3 feet for d from the above formula, which more or less fits in with the actual fall in the M.S.L. noticed during this period from the graphs of Chart XXXIII. This would go to show that the apparent changes in the M.S.L. have only been consequent on the hydrographic changes in the river and are not due to any change in the coastal elevation at Kidderpore. That no coastal subsidence or emergence has occurred at Kidderpore is corroborated by our recent levelling operations, as will be shown in para 4 below.

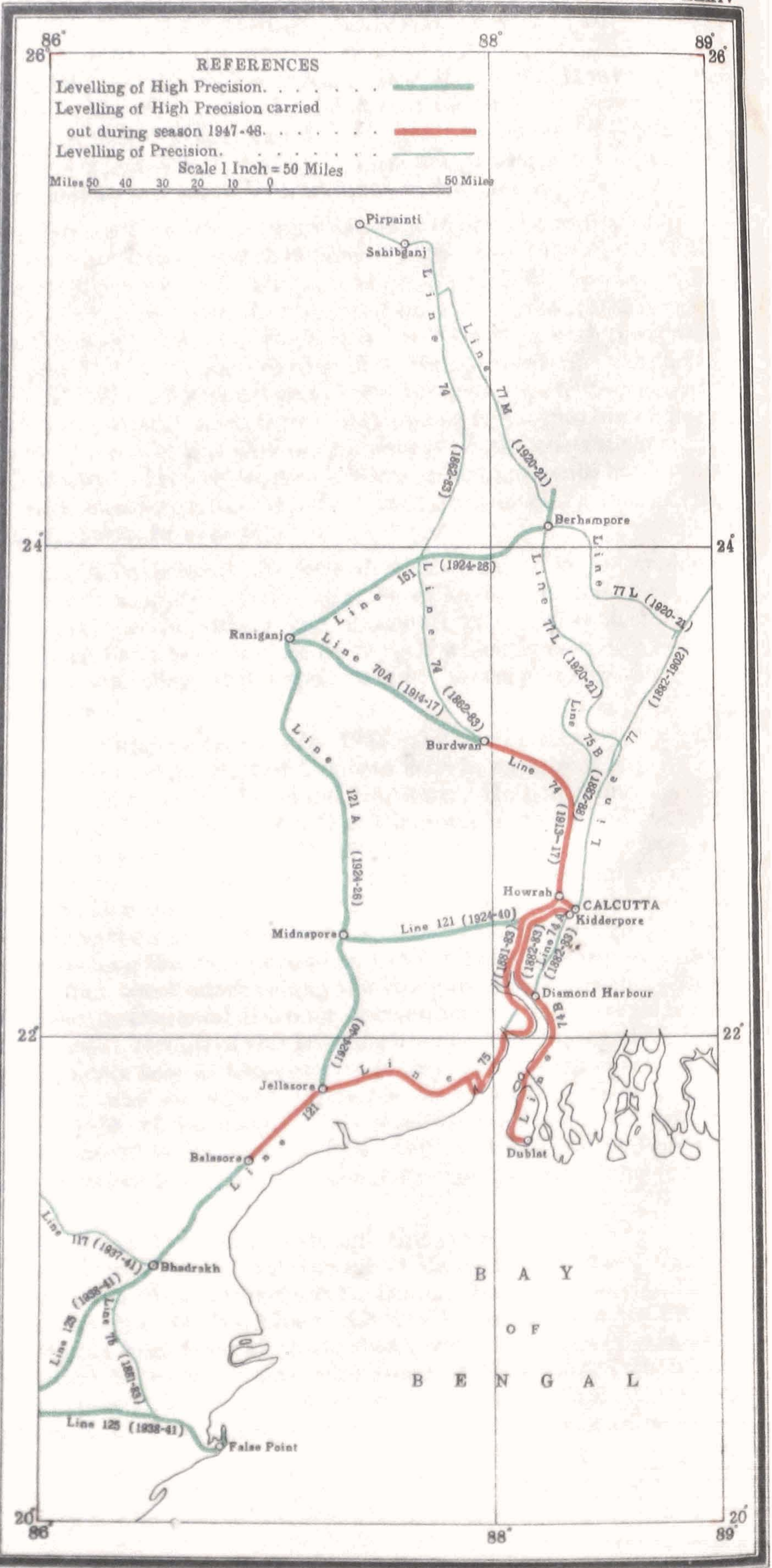
It might be pointed out here that Kidderpore is not an ideal port for such a study. It is about 80 miles up the river and the freshets play an important but unknown role. New systematic observations have been started at Saugor which is near the mouth of the river and these, it is hoped, would be very useful for such investigations.

4. **Levelling evidence.**—In 1947, the River Surveyor to the Commissioners for the Port of Calcutta sent in an urgent requisition for some levelling round Diamond Harbour. He had found by his local levelling that B.M. 159/79 B at Diamond Harbour had sunk by about 6 inches relative to B.M. 160/79 B in the same locality and he wanted to make sure as to which was the one that he could use as a reliable starting B.M. for fixing the zeroes of some of his gauges along the river as the heights of bench-marks of reference of his gauges along the river depend on these values. He reported that all the other bench-marks along the Hooghly River especially from Falta point to Diamond Harbour were either missing or reported to be disturbed. Details of this levelling are given in Chapter II, where it is explained how in the absence of any stable rock-cut B.M. at Calcutta it was considered advisable to extend the levelling to standard B.M. at Burdwān. This levelling confirmed the sinkage of B.M. 159/79 B relative to B.M. 160/79 B and in addition has furnished valuable information about the general subsidence of the delta area.

The original levelling through this area was carried out in 1881–83, from Pirpainti to Howrah, (Main-line No. 74 of the old level net) and from Kidderpore to Dublat via Diamond Harbour, Branch-line No. 74 B (Chart XXXIV). In 1913 most of the bench-marks from Howrah to Burdwān were reported as destroyed. A standard bench-mark was established at Burdwān in 1910 and again connected by levelling from Benares in 1914–15. A line was run from Howrah to Champdāni in 1913–14 and from Champdāni to

LEVELLING LINES OF HIGH PRECISION AND PRECISION

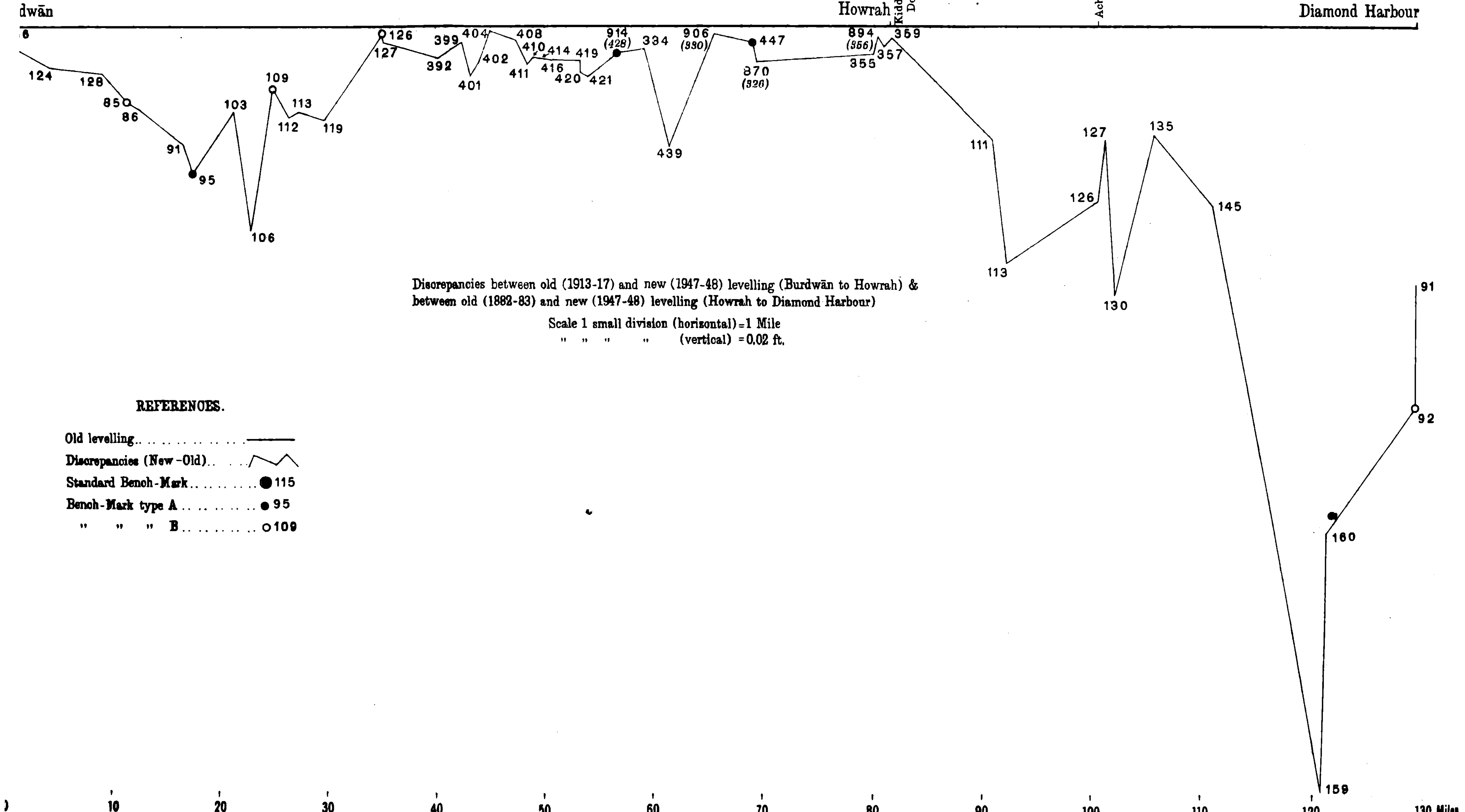
Chart XXXIV



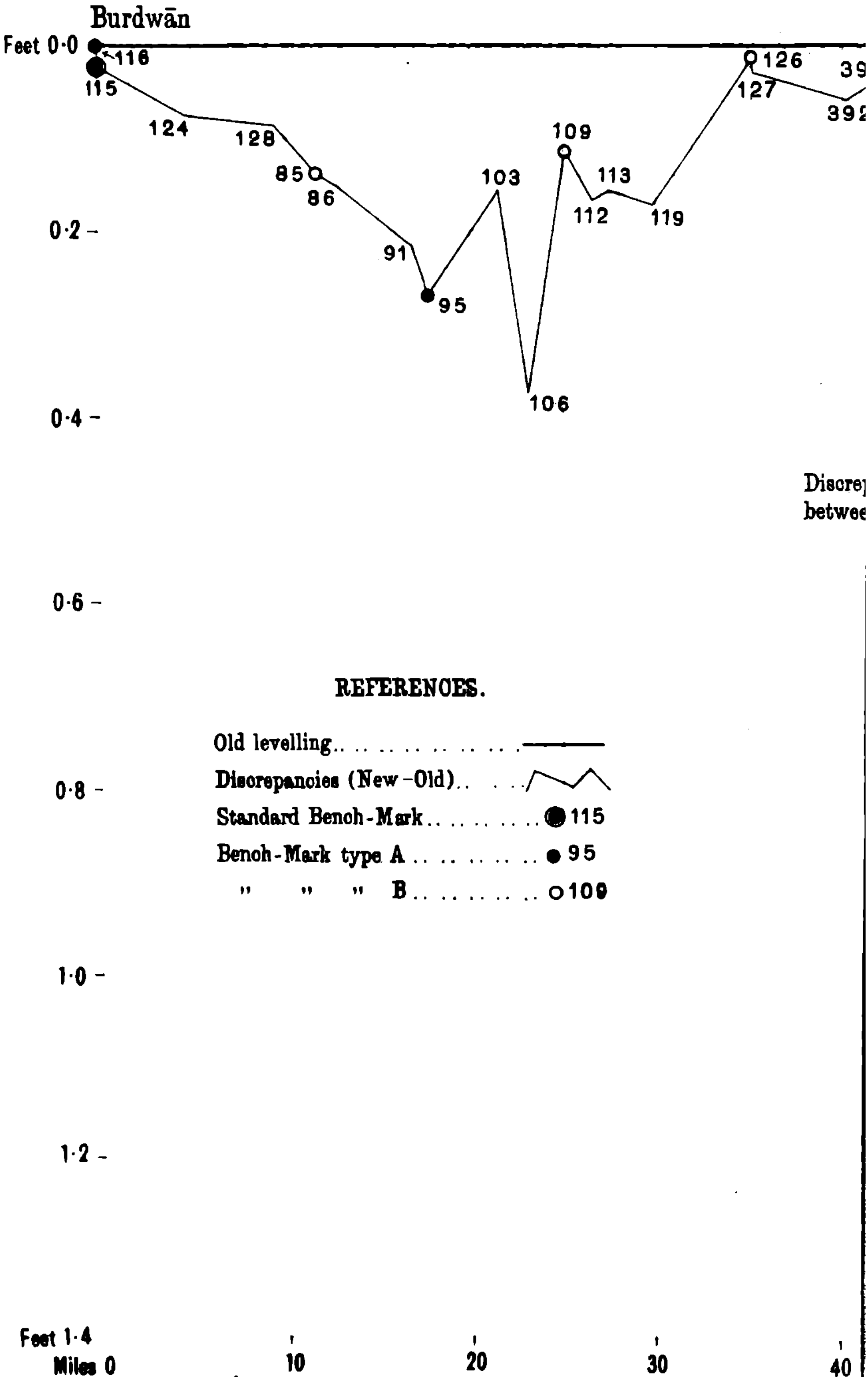
Reg. No. 600 M/N.C.D'50(G&T.C)-376. Printed at the Survey of India Offices.(P.Z.O.).

OLD AND NEW LEVELLING
FROM
BURDWĀN TO DIAMOND HARBOUR

Chart XXXV



890 M/N.C. D'50 (G. & T. C.)-375.
Printed at the Survey of India Offices, (P. Z. O.).



Reg. No. 390 M/N.C. D'30 (G. & T. C.)-375.

Burdwān in 1916–17, the closure being effected on the standard bench-mark at Burdwān.

In trying to delineate subsidence of an area by levelling, it is essential to start the levelling from a stable bench-mark, preferably on rock and carry it on to good bench-marks of the suspected area where previous heights are known. The levelling of 1913–16 was not carried out with the idea of detecting such secular changes and it did not therefore connect any bench-marks of the older levelling of 1881–83. In running the new line from Burdwān to Diamond Harbour, therefore, a careful search was made for all old bench-marks and as many as could be identified were carefully connected. Table 6 shows the differences in the values of these bench-marks by the old and new levellings in terms of B.M. 116/73 M at Burdwān. These differences are plotted graphically in Chart XXXV which exhibits some interesting features.

The sudden discontinuities indicate irregular local sinkage of bench-marks but there are systematic trends to be discerned also. The region between B.M. 126 and Howrah has remained practically undisturbed (except for one solitary B.M. 439), but on either side of it there are 'V' shaped depressions, which can be attributed to the general downwarping of these areas. The portion from Howrah to Diamond Harbour especially in the vicinity of the latter is violently disturbed. In the neighbourhood of Achipur, subsidence since 1882–83 is of the order of 0·3 feet, but it is very much greater at Diamond Harbour where B.M. 159 has subsided by as much as 1·4 feet, B.M. 160 by 0·9 feet and B.M. 92 by 0·7 feet. Curiously enough, Kidderpore Dock does not seem to have altered. This is probably due to the B.M. being on piles driven well into the sea. The above changes are much more than the errors of levelling and must be regarded as real. Such changes, however, can be normally expected in an area composed of deltaic alluvium. Individual and highly discrepant sinkages occur because of the existence of quicksands and of supersaturated beds and lack of uniformity from place to place in the alluvial strata. They do not represent a general subsidence of the crust.

It appears thus to be essential to have a group of bench-marks of suitable pattern in this region which should be reconnected at frequent intervals to keep track of local and regional changes of level.

That the immediate region round Calcutta has not changed is also proved by the fact that the check-levellings carried out at different periods have shown that many bench-marks have retained their original heights since 1882–83.

Further levelling has been done on the right bank of the Hooghly and will be extended to False point to get it in terms of independent M.S.L. Full discussion will be given in the next Technical Report.

5. **Conclusion.—From the data available, no firm conclusions can be drauw about the vertical deformations of the crust in S. Bengal.**

The region in the vicinity of Calcutta appears to have remained more or less stable, while to the south in the region round Diamond Harbour there are large and irregular sinkages of bench-marks. These are to be taken more as local individual subsidences rather than regional downwarping of the crust. Such downwarping is generally very small and even with sufficient data great care and experience is needed for its delineation. The levelling data has its severe limitations in such areas as the deltaic portions of Bengal as the bench-marks are liable to individual sinkages which are not at all representative of the general downwarping of the crust.

For a riverain port like Kidderpore 80 miles above the mouth of the river the tidal data also has its peculiar difficulties. Such non-tidal factors as freshets and shallow water corrections can vitiate the conclusions. There is also the added uncertainty that the port authorities do not generally realize the importance of ensuring that the zero of tide-gauge should remain undisturbed. Cases are not wanting where this datum has been changed lightly through ignorance resulting in a break in the continuity of the observations.

TABLE 1.—*Kidderpore* (*Calcutta*)

Annual Mean Sea-Level

Year	M.S.L.	Year	M.S.L.	Year	M.S.L.
	feet		*feet*		*feet*
1881–82	10·739	1911	10·781	1941	10·34
1882–83	10·686	1912	10·314	1942	10·70
1883–84	10·599	1913	10·495	1943	10·62
1884–85	10·669	1914	10·313	1944	10·09
1885–86	10·950	1915	10·453	1945	10·22
1886–87	11·383	1916	10·804	1946	10·36
1887–88	11·080	1917	10·807	1947	10·54
1888–89	10·842	1918	10·318	1948	10·52
1889–90	11·232	1919	10·382	1949	10·18
1890–91	11·364	1920	10·169	**Mean 1941-49**	**10·40**
Mean 1881-90	**10·954**	**Mean 1911-20**	**10·484**		
1891–92	10·618	1921	10·35		
1892–93	10·817	1922	10·83		
1893	11·292	1923	10·12		
1894	11·383	1924	10·70		
1895	10·476	1925	10·13		
1896	10·123	1926	10·22		
1897	10·535	1927	10·21		
1898	10·858	1928	10·59		
1899	10·660	1929	10·39		
1900	10·604	1930	10·36		
Mean 1891-1900	**10·737**	**Mean 1921-30**	**10·39**		
1901	10·358	1931	10·43		
1902	10·398	1932	9·98		
1903	10·711	1933	10·36		
1904	10·830	1934	10·09		
1905	10·593	1935	9·78		
1906	10·722	1936	10·46		
1907	10·358	1937	10·34		
1908	10·397	1938	10·71		
1909	10·770	1939	10·55		
1910	10·895	1940	10·00		
Mean 1901-10	**10·603**	**Mean 1931-40**	**10·27**		

NOTE.—From 1881 to 1893 the year in the above Table refers to the period April to March.

TABLE 2.—*Kidderpore* (*Calcutta*) *M.S.L.*

(9-Yearly Means)

Years	Mean	Years	Mean	Years	Mean
	feet		*feet*		*feet*
1881–90	10·91	1901–09	10·57	1921–29	10·39
82–91	10·98	02–10	10·63	22–30	10·39
83–92	10·97	03–11	10·67	23–31	10·36
84–93	11·00	04–12	10·63	24–32	10·34
85–93	11·06	05–13	10·51	25–33	10·30
86–94	11·11	06–14	10·56	26–34	10·29
87–95	11·01	07–15	10·53	27–35	10·24
88–96	10·90	08–16	10·58	28–36	10·27
89–97	10·87	09–17	10·63	29–37	10·24
1890–98	10·83	1910–18	10·58	1930–38	10·28
1891–99	10·75	1911–19	10·52	1931–39	10·30
92–1900	10·75	12–20	10·45	32–40	10·25
93–01	10·70	13–21	10·46	33–41	10·29
94–02	10·60	14–22	10·49	34–42	10·33
95–03	10·52	15–23	10·47	35–43	10·39
96–04	10·56	16–24	10·50	36–44	10·42
97–05	10·62	17–25	10·42	37–45	10·40
98–06	10·64	18–26	10·36	38–46	10·40
1899–07	10·58	19–27	10·35	39–47	10·38
1900–08	10·55	1920–28	10·37	1940–48	10·38
				1941–49	10·40

TABLE 3.—*Kidderpore* (*Calcutta*) *M.S.L.*

(19-Yearly Means)

Years	Mean	Years	Mean	Years	Mean
	feet		*feet*		*feet*
1881–99	10·86	1901–19	10·56	1921–39	10·35
82–1900	10·85	02–20	10·56	22–40	10·33
83–01	10·83	03–21	10·55	23–41	10·30
84–02	10·82	04–22	10·56	24–42	10·33
85–03	10·82	05–23	10·52	25–43	10·33
86–04	10·82	06–24	10·52	26–44	10·33
87–05	10·78	07–25	10·49	27–45	10·33
88–06	10·76	08–26	10·49	28–46	10·34
89–07	10·73	09–27	10·48	29–47	10·33
1890–08	10·69	1910–28	10·47	30–48	10·34
1891–1909	10·66	1911–29	10·44	1931–49	10·33
92–10	10·67	12–30	10·42		
93–11	10·67	13–31	10·42		
94–12	10·62	14–32	10·40		
95–13	10·57	15–33	10·40		
96–14	10·56	16–34	10·38		
97–15	10·58	17–35	10·33		
98–16	10·60	18–36	10·31		
99–17	10·54	19–37	10·31		
1900–18	10·58	1920–38	10·33		

TABLE 4.—*Luni-tidal intervals at Kidderpore for High and Low Water—mean monthly values for 1882 and 1948.*

(Interval has been calculated from Greenwich Meridian)

Months	High Water 1882		High Water 1948		Low Water 1882		Low Water 1948		REMARKS
	h	m	h	m	h	m	h	m	
January ..	1	25	1	46	9	32	9	56	
February ..	1	19	1	48	9	26	10	04	
March ..	1	19	1	33	9	28	9	52	
April ..	1	16	1	21	9	25	9	39	
May ..	1	12	1	15	9	15	9	25	
June ..	0	55	1	20	9	06	9	30	
July ..	0	40	1	17	9	02	9	32	
August ..	0	36	0	59	9	14	9	31	
September ..	0	34	0	58	9	09	9	39	
October ..	0	44	1	09	9	13	9	47	
November ..	1	11	1	23	9	20	9	39	
December ..	1	17	1	42	9	11	9	53	
Mean ..	1	02	1	22	9	17	9	42	
	Diff. + 20 mins.				Diff + 25 mins.				

TABLE 5.—*Luni-tidal intervals at Dublat (Saugor) for High and Low Water—mean monthly values for 1882 and 1941.*

Interval has been calculated from Greenwich Meridian

Months	High Water 1882		High Water 1941		Low Water 1882		Low Water 1941		REMARKS
	h	m	h	m	h	m	h	m	
January ..	9	27	9	56	15	58	16	31	
February ..	9	23	9	57	15	55	16	33	
March ..	9	28	9	52	16	03	16	27	
April ..	9	20	9	47	15	54	16	16	
May ..	9	18	9	42	15	49	16	09	
June ..	9	02	9	41	15	33	16	10	
July ..	9	04	9	40	15	31	16	07	
August ..	9	06	9	42	15	34	16	04	
September ..	9	01	9	45	15	34	16	12	
October ..	9	12	9	47	15	39	16	15	
November ..	9	18	9	49	15	46	16	19	
December ..	9	21	9	52	15	49	16	23	
Mean ..	**9**	**15**	**9**	**48**	**15**	**45**	**16**	**17**	
	Diff. + 33 mins.				**Diff. + 32 mins.**				

TABLE 6.—*Old and new Levelling from Burdwān to Diamond Harbour.*

B.M. Nos.	Brief description	Distance from B.M. 116/73M at Burdwān	Date of original levelling	Observed differential heights between consecutive bench-marks from original levelling	Observed differential heights between consecutive bench-marks from new levelling	Discrepancy (New—old)	Discrepancy from B.M. 116/73M at Burdwān
		Miles		*feet*	*feet*	*feet*	*feet*
73 M							
116	Burdwān, (Type A) ..	0·0	1913–17	0·000	0·000	0·000	0·000
115	Burdwān S.B.M. ..	0·0	,,	+ 5·118	+ 5·095	− 0·023	− 0·023
124	Bridge ..	4·7	,,	− 4·870	− 4·921	− 0·051	− 0·074
128	Sonakūr T.S. ..	9·6	,,	−10·355	−10·368	− 0·013	− 0·087
79 A							
85	Balut village, (Type B)	11·7	,,	− 9·056	− 9·108	− 0·052	− 0·139
86	Rasulpur Rly. Station Platform ..	12·9	,,	+ 5·277	+ 5·266	− 0·011	− 0·150
91	Memari Rly. Station Platform ..	16·9	,,	− 7·972	− 8·039	− 0·067	− 0·217
95	Memari, (Type A) ..	17·7	,,	−11·267	−11·319	− 0·052	− 0·269
103	Bridge ..	21·5	,,	− 3·081	− 2·968	+ 0·113	− 0·156
106	Step of tank ..	23·2	,,	− 2·030	− 2·249	− 0·219	− 0·375
109	Edge of field (Type B)	25·1	,,	−11·792	−11·530	+ 0·262	− 0·113
112	Road boundary pillar ..	26·6	,,	+ 2·727	+ 2·674	− 0·053	− 0·166
113	Simlagarh Rly. Station Platform ..	27·4	,,	+ 3·042	+ 3·051	+ 0·009	− 0·157
119	Road boundary pillar ..	29·9	,,	− 4·865	− 4·881	− 0·016	− 0·173
126	Khonean village (Type B) ..	35·3	,,	−12·297	−12·140	+ 0·157	− 0·016
127	Culvert ..	35·4	,,	− 1·099	− 1·113	− 0·014	− 0·030
79 B							
392	Abutment of bridge ..	40·4	,,	− 1·674	− 1·702	− 0·028	− 0·058
399	Parapet of well ..	42·5	,,	+ 7·567	+ 7·593	+ 0·026	− 0·032
401	Rly. culvert No. 85 ..	43·3	,,	− 2·187	− 2·244	− 0·057	− 0·089
402	Rly. bridge No. 3 ..	44·1	,,	− 4·143	− 4·120	+ 0·023	− 0·066
404	Culvert ..	45·0	,,	− 0·276	− 0·218	+ 0·058	− 0·008
408	Culvert ..	47·4	,,	− 3·075	− 3·092	− 0·017	− 0·025
411	Stone slab, Chinsura Circuit house ..	48·6	,,	+ 0·004	− 0·041	− 0·045	− 0·070
410	Base of Clock tower ..	49·1	,,	+ 2·148	+ 2·161	+ 0·013	− 0·057
414	Seat of entrance gate ..	49·6	,,	+ 0·184	+ 0·181	− 0·003	− 0·060
416	Parapet of culvert ..	50·6	,,	− 2·193	− 2·195	− 0·002	− 0·062
419	Masonry pavement ..	53·3	,,	− 3·403	− 3·406	− 0·003	− 0·065
420	Step, Chandernagore ..	53·4	,,	+ 1·431	+ 1·412	− 0·019	− 0·084
421	Flooring, Telipāra ..	54·0	,,	+ 0·847	+ 0·838	− 0·009	− 0·093
914	Champdani, (Type A) ..	56·7	,,	− 3·441	− 3·397	+ 0·044	− 0·049
(*428*) 334	Bridge ..	59·2	,,	− 0·521	− 0·514	+ 0·007	− 0·042
439	Serampur Rly. Station. Platform	61·4	,,	+ 2·878	+ 2·702	− 0·176	− 0·218
906	Konnagar Bathing Ghat	65·5	..	− 7·960	− 7·756	+ 0·204	− 0·014
(*330*) 447	Uttarpara, (Type A) ..	69·0	..	+ 1·897	+ 1·883	− 0·014	− 0·028

(*Continued*)

TABLE 6.—*Old and new levelling from Burdwān to Diamond Harbour.*—(concld.)

B.M. Nos.	Brief description	Distance from B.M. 116/73M at Burdwān	Date of original levelling	Observed differential heights between consecutive bench-marks from original levelling	Observed differential heights between consecutive bench-marks from new levelling	Discrepancy (New–old)	Discrepancy from B.M. 116/73M at Burdwān
		Miles		*feet*	*feet*	*feet*	*feet*
79 B 870 (*326*)	Bridge ..	69·4	1913–17	+ 4·876	+ 4·839	− 0·037	− 0·065
355	Marble step ..	79·9	1881–83	− 2·704	− 2·692	+ 0·012	− 0·053
894 (*356*)	Step of statue ..	80·3	,,	− 0·024	+ 0·049	+ 0·073	+ 0·020
357	Pavement, Hasting's bridge ..	80·9	,,	+ 8·617	+ 8·561	− 0·056	− 0·036
359	Kidderpore New Dock	81·5	,,	−13·723	−13·666	+ 0·057	+ 0·021
111	Top of marine socket ..	90·8	,,	+ 1·328	+ 1·101	− 0·227	− 0·206
113	Top of marine socket ..	92·2	,,	− 0·472	− 0·697	− 0·225	− 0·431
126	Step, Achipur telegraph office ..	100·5	,,	− 4·276	− 4·163	+ 0·113	− 0·318
127	Stone slab, Mayapur Tidal Semaphore ..	101·1	,,	− 1·299	− 1·187	+ 0·112	− 0·206
130	Stone slab, Mayapur Magazine ..	102·1	,,	+ 0·952	+ 0·671	− 0·281	− 0·487
135	Top of marine socket ..	105·6	,,	+ 0·984	+ 1·273	+ 0·289	− 0·198
145	Top of marine socket ..	110·8	,,	+ 0·675	+ 0·549	− 0·126	− 0·324
159	Hooghly Point, Tidal Semaphore ..	120·7	,,	− 0·679	− 1·749	− 1·070	− 1·394
160	Step, Hooghly Point, P.W.D., I.B. ..	121·1	,,	− 1·432	− 0·957	+ 0·475	− 0·919
92	Diamond Harbour, (Type B) ..	129·1	,,	+ 6·675	+ 6·903	+ 0·228	− 0·691
91	Step, Diamond Harbour, P.W.D., I.B. ..	129·1	,,	− 7·902	− 7·683	+ 0·219	− 0·472

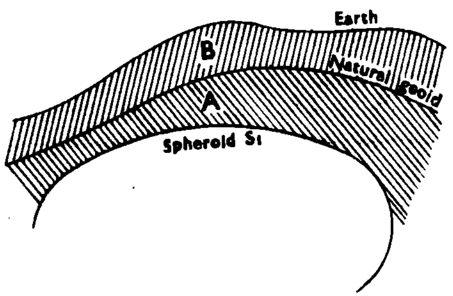
SECTION III—GEOIDS

1. The study of deflections in India on some sort of a systematic basis started in the beginning of this century (see Professional Paper No. 5, Survey of India 1901). In those days, the data was sparse and the plumb-line deflections were plotted and shown vectorially by arrows. Certain important characteristics about their distribution were noticed, such as their being deflected away from the Himālayas in Central India and pointing towards a line in the plains. As more and more data accumulated it was considered that to make a detailed study of the hidden mass anomalies in the earth's crust, it was better to study the rise of the geoid which can be regarded as a synthesis of the deflections rather than individual values of deflections.

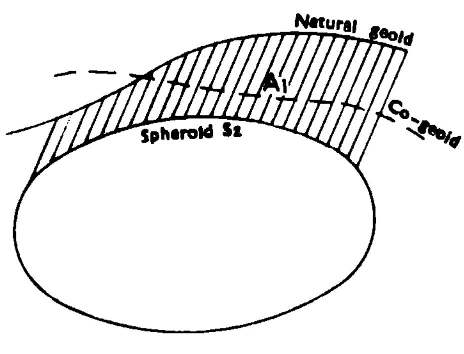
Reliable charts showing the different types of geoids were started in the Survey of India in about 1928 (see Geodetic Report Vol. V, Charts IX, X, XI and XII). These geoidal charts have provided a broad framework for the study of deep seated effects well below the limit of geophysical prospecting. The next step is to narrow down this framework further and further till true knowledge of superficial effects is gained.

Unfortunately the definitions of geoids given on page 57 of Geodetic Report Vol. V are all incorrect. They are accordingly set down in the next para. It is important to put them down clearly as there is no uniformity about their nomenclature and different countries are apt to designate them differently.

2. Natural geoid or Geoid : This is simply the sea-level equipotential surface of the matter comprising the whole earth. It may be reckoned as equipotential of a reference spheroid S_1 + matter A between this spheroid and the geoid + matter B between the geoid and the earth.

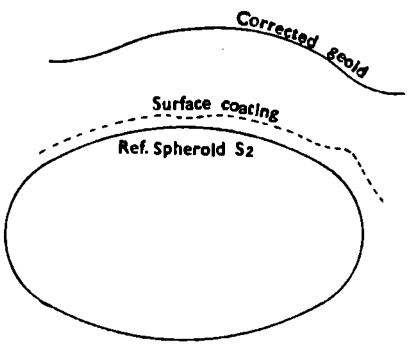


Compensated geoid or Co-geoid : If the topographic masses B between the geoid and the earth be removed together with their compensation, the level surface of the new mass system is called the co-geoid. The new system of masses of which co-geoid is the level surface may be represented by reference spheroid S_2 + matter A_1.



Obviously all the attracting masses are not external to the co-geoid as some parts of A_1 lie above it.

Corrected Geoid : For many purposes, it is necessary to have a level surface which has no masses external to it. This can be achieved by further modifying the topography by condensing it on reference spheroid S_2. The equipotential of the new mass system having the same potential as the spheroid S_2 is called the corrected geoid.



Isostatic Geoid : This is the theoretical geoid obtained by assuming isostasy to be perfect in all detail. Its height above its reference spheroid can be computed theoretically by calculating the warping produced by the topography and its compensation.

If earth were in isostatic equilibrium, compensated geoid would be a perfect spheroid but not so the isostatic geoid. This will coincide with the natural geoid.

If, however, as is the actual case, isostasy is not perfect, then deviation of compensated geoid from its reference spheroid gives a measure of the non-fulfilment of isostasy. Some countries particularly the U.S.A. call Co-geoid as Isostatic geoid, so it is necessary to be clear about the definitions.

Chart XXIV of this Report shows the compensated geoid in India.

3. Normally the observed gravity is reduced to co-geoid and is compared against γ_0 the value on the reference spheroid computed theoretically. The conventional isostatic anomaly ($g_c - \gamma_0$) $= \Delta g_c$ is due to three causes :

(*a*) Distance N between co-geoid and spheroid.
(*b*) Matter N between these surfaces.
(*c*) Anomalous masses.

In India the natural geoid has been derived from observed plumb-line deflections and not from gravity data. Compensated geoid can be derived by integrating Hayford deflection anomalies but since these are laborious to compute, it was derived from the natural geoid by subtracting the height of the isostatic geoid from it. Elevation u of the isostatic geoid above its spheroid was calculated theoretically by considering the effect of topography and its compensation. There is a little irregularity involved here as the conditions under which u is calculated are that masses of geoid and spheroid are the same. This condition is not necessarily satisfied for the geoids determined from plumb-line deflections and their reference spheroids but the method has been checked by integrating directly some Hayford deflection anomalies. The results agree to within 1 foot.

4. Orientation of International spheroid in India.—A reference spheroid in triangulation is a true spheroid which has to be defined by the following seven constants :—

ζ_0 the angle between the spheroidal and geoidal normals at the geodetic datum.

A_0 the angle which the plane containing the above two normals makes with the geoidal meridian.

N_0 the vertical separation between the spheroid and the geoid at the datum.

β, γ the direction cosines of its minor axis.

a, ϵ its semi-major axis and ellipticity.

It is not possible to give anything that can be described as the International values of deflection at Kaliānpur which is the datum of Indian triangulation. An attempt, however, was made in 1926 to derive values (η_0, ξ_0) of plumb-line deflections at Kaliānpur which would have given a best fit between a spheroid with International axes and the compensated geoids then known. At 12 points, the rise of the compensated geoid was taken and equations were written so as to make $\Sigma (N + \delta N)^2$ a minimum. It was found, that $\eta_0 = + 2'' \cdot 42$, $\xi_0 = - 3'' \cdot 17$, $N_0 = 31$ feet gave the best agreement between the compensated geoid and the spheroid with International axes. These values have since been adopted for the orientation of International spheroid in India.

It might be remarked, however, that much more deflection data has accummulated since 1926 and the present chart of the compensated geoid besides marked extension of knowledge to the east presents salient differences from the older Chart XI of Geodetic Report Vol. V. A new solution would no doubt give different values for (η_0, ξ_0, N_0), and so the quotation of two figures of decimals in η_0 and ξ_0 and nearest foot in N_0 should not be regarded as connoting corresponding accuracy. These values may be regarded as part of the definition of the International spheroid in India.

It would also be seen from the above that the International Spheroid is fitted to the geoid in a geometrical rather than in the physical sense as its centre of gravity does not coincide with that of the co-geoid. The absolute deflections at the datum can only be found from the gravity anomalies and these have not been utilized in our orientation of the co-geoid.

5. Masses external to the geoid : It would be apparent from the definition of the co-geoid that it has masses external to it. This presents a great complication as in order to get the form of a level surface from gravity anomalies on it, it is essential that there should be no masses protruding beyond it. The co-geoid has thus to be reduced one step further by removing the masses between the co-geoid and the natural geoid. These masses are by no means negligible and produce considerable warping of the level surfaces. Their treatment presents great difficulties and geodesists are not yet agreed as to how they should be finally disposed off.

LIST OF IMPORTANT GEODETIC PUBLICATIONS AND CONTRIBUTIONS BY OFFICERS OF THE SURVEY OF INDIA

(A) Publications.

No.	*Name of Book*	*Details*
1.	G.T.S. Vol. II	**History and General Description of the Reduction of the Principal Triangulation.** Dehra Dūn, 1879. *Price Rs. 10-8.*
2.	G.T.S. Vol. IX	**Telegraphic Longitudes.** During the years 1875–77 and 1880–81. Dehra Dūn, 1883. *Price Rs. 10-8.*
3.	G.T.S. Vol. X	**Telegraphic Longitudes.** During the years 1881–82, 1882–83 and 1883–84. Dehra Dūn, 1887. *Price Rs. 10-8.*
4.	G.T.S. Vol. XI	**Astronomical Latitudes.** During the period 1805–1885. Dehra Dūn, 1890. *Price Rs. 10-8.*
5.	G.T.S. Vol. XV	**Telegraphic Longitudes.** From 1885 to 1892 and the Revised Results of Vols. IX and X: also the Simultaneous Reduction and final Results of the whole Operations. Dehra Dūn, 1893. *Price Rs. 10-8.*
6.	G.T.S. Vol. XVI	**Tidal Observations.** From 1873 to 1892 and the Methods of Reduction. Dehra Dūn, 1901. *Price Rs. 10-8.*
7.	G.T.S. Vol. XVII	**Telegraphic Longitudes.** During the years 1894–95–96. The Indo-European Arcs from Karāchi to Greenwich. Dehra Dūn, 1901. *Price Rs. 10-8.*
8.	G.T.S. Vol. XVIII	**Astronomical Latitudes.** From 1885 to 1905 and the deduced values of Plumb-line Deflections. Dehra Dūn, 1906. *Price Rs. 10-8.*
9.	G.T.S. Vol. XIX	**Levelling of Precision in India.** From 1858 to 1909. Dehra Dūn, 1910. *Price Rs. 10-8.*
10.	Records of the Survey of India, Vol. XIX	1901–20. The Magnetic Survey, by Lt.-Colonel R. H. Thomas, D.S.O., R.E. and E. C. J. Bond, V.D. Dehra Dūn, 1925. *Price Rs. 4.*

No.	*Name of Book*	*Details*
11.	Geodetic Report Vol. I	1922–25. Computations and Research. Tidal work. Time and Magnetic observations. Latitude and Pendulum observations in Bihār, Assam and Kashmīr. Levelling. Lecture on "The height of Mount Everest and other Peaks". Dehra Dūn, 1928. *Price Rs. 6.*
12.	Geodetic Report Vol. II	1925–26. Computations and Research. Tidal work. Time and Magnetic observations. Preparations for the International Longitude Project. Triangulation. Levelling. Investigation of the behaviour of tree bench-marks in India. Dehra Dūn, 1928. *Price Rs. 3.*
13.	Geodetic Report Vol. III	1926–27. The International Longitude Project. Computations and Publication of data. Observatories. Tides. Gravity and Deviation of the Vertical. Triangulation. Levelling. Research and Technical Notes regarding Personal Equation Apparatus and the height of Mount Everest. Dehra Dūn, 1929. *Price Rs. 3.*
14.	Geodetic Report Vol. IV	1927–28. Computations and Publication of data. Observatories. Tides. Gravity and Deviation of the Vertical. Triangulation. Levelling. Dehra Dūn, 1929. *Price Rs. 3.*
15.	Geodetic Report Vol. V	1928–29. Computations and Publication of data. Observatories. Tides. Gravity and Deviation of the Vertical. Triangulation. Levelling. Research and Technical Notes. Dehra Dūn, 1930. *Price Rs. 3.*
16.	Geodetic Report Vol. VI	1929–30. Computations and Publication of data. Observatories. Tides. Gravity. Triangulation. Levelling. Research and Technical Notes. Dehra Dūn, 1931. *Price Rs. 3.*
		Supplement. Indian Deflection and Gravity stations. Dehra Dūn, 1931. *Price Rs. 1-8.*
17.	Geodetic Report Vol. VII	1930–31. Computations and Publication of data. Observatories. Tides. Deviation of the Vertical. Gravity. Triangulation and Base Measurement. Levelling. The Magnetic Survey. Dehra Dūn, 1932. *Price Rs. 3.*

No.	*Name of Book*	*Details*
18.	Geodetic Report Vol. VIII	1931–32. Computations and Publication of data. Observatories. Tides. Gravity. Triangulation. Levelling. Research and Technical Notes. Dehra Dūn, 1933. *Price Rs. 3.*
19.	Geodetic Report 1933	Triangulation and Base Measurement. Levelling. Deviation of the Vertical. Computations and Publication of data. Observatories. Tides. Research and Technical Notes. Dehra Dūn, 1934. *Price Rs. 3.*
20.	Geodetic Report 1934	Triangulation and Base Measurement. Levelling. Gravity. Deviation of the Vertical. Computing Office and Tidal Section. The International Longitude Project. Observatories. Research and Technical Notes. Dehra Dūn, 1935. *Price Rs. 3.*
21.	Geodetic Report 1935	Triangulation. Levelling. Deviation of the Vertical. Gravity. Geophysical Survey in Bihār. Computing Office and Tidal Section. Observatories. Research and Technical Notes. Dehra Dūn, 1936. *Price Rs. 3.*
22.	Geodetic Report 1936	Triangulation. Levelling. Deviation of the Vertical. Gravity. Computing Office and Tidal Section. Observatories. Subsoil Water Levels. Levelling in Bengal and Bihār. Dehra Dūn, 1937. *Price Rs. 3.*
23.	Geodetic Report 1937	Triangulation. Levelling. Gravity. Magnetic Survey in Bihār. Computing Office and Tidal Section. Observatories. Dehra Dūn, 1938. *Price Rs. 3.*
24.	Supplement to Geodetic Report 1937	Isostatic reductions of Indian Gravity Stations. Dehra Dūn, 1939. *Price Rs. 2-8.*
25.	Geodetic Report 1938	Triangulation and Levelling. Deviation of the Vertical. Gravity. Computing Office and Tidal Section. Observatories. Dehra Dūn, 1939. *Price Rs. 3.*
26.	Geodetic Report 1939	Levelling. Gravity. Computing Office and Tidal Section. Observatories. Research and Technical Notes. Dehra Dūn, 1940. *Price Rs. 3.*
27.	Geodetic Report 1940	Levelling. Deviation of the Vertical Gravity. Computing Office and Observatories. Dehra Dūn, 1945. *Price Rs. 2-*

No.	*Name of Book*	*Details*
28.	Technical Report, Part III, Geodetic Work 1947	Triangulation in the Neighbouring Countries of India. Levelling. Gravity. Deviation of the Vertical. Computations and Publications. Tides. Observatories. Dehra Dūn, 1948. *Price Rs. 4.*
29.	Technical Report, Part III, Geodetic Work 1948-49.	Triangulation. Levelling. Gravity. Deviation of the Vertical. Tides. Observatories. Computations and Publications. Research and Technical Notes. Dehra Dūn, 1950. *Price Rs. 4.*
30.	Professional Paper No. 10	**Pendulums.** The Pendulum Operations in India, 1903–07, by Maj. G. P. Lenox-Conyngham, R.E. Dehra Dūn, 1908. *Price Rs. 2-8.*
31.	Professional Paper No. 15	**Pendulums.** The Pendulum Operations in India and Burma, 1908–13, by Capt. H. J. Couchman, R.E. Dehra Dūn, 1915. *Price Rs. 2-8.*
32.	Professional Paper No. 16	**Geodesy.** The Earth's Axes and Triangulation, by J. de Graaff Hunter, M.A. Dehra Dūn, 1918. *Price Rs. 4.*
33.	Professional Paper No. 22	**Levelling.** Three Sources of error in Precise Levelling, by Capt. G. Bomford, R.E. Dehra Dūn, 1929. *Price Rs. 1-8.*
34.	Professional Paper No. 27	**Gravity.** Gravity Anomalies and the Structure of the Earth's Crust, by Maj. E. A. Glennie, D.S.O., R.E. Dehra Dūn, 1932. *Price Rs. 1-8.*
35.	Professional Paper No. 28	**Triangulation.** The Readjustment of the Indian Triangulation, by Maj. G. Bomford, R.E. Dehra Dūn, 1938. *Price Rs. 4-8.*
36.	Professional Paper No. 29	**Magnetic.** Magnetic Anomalies, by B. L. Gulatee, M.A. (Cantab.). Dehra Dūn, 1938. *Price Rs. 1-8.*
37.	Professional Paper No. 30	**Gravity.** Gravity Anomalies and the Figure of the Earth, by B. L. Gulatee, M.A. (Cantab.). Dehra Dūn, 1940. *Price Rs. 3.*
38.	War Research Series Pamphlet No. 9	**The Trans-Persia Triangulation 1941–44.** (linking Irāq and India), by J. de Graaff Hunter, C.I.E., SC.D., F.R.S. and B. L. Gulatee, M.A. (Cantab.), with an Appendix "The Persia–India Connection", by Maj. P. A. Thomas, I.E. *Price Rs. 2.*

No.	*Name of Book*	*Details*
39.	Memoirs of The Survey Research Institute Vol. 1, No. 1	Geophysical Prospecting for Manganese near Rāmtek, C. P., by B. L. Gulatee, M.A. (Cantab.). *Price Rs. 3.*
40.	Technical Paper No. 2	Value of Gravity at Dehra Dūn, by Mr. B. L. Gulatee, M.A. (Cantab.). Dehra Dūn, 1948.
41.	Technical Paper No. 3	Levelling in India, Past and Future, by, Mr. B. L. Gulatee, M.A. (Cantab.). Dehra Dūn, 1949.
42.	Technical Paper No. 4	Mount Everest, its Name and Height, by Mr. B. L. Gulatee, M.A. (Cantab.). Dehra Dūn, 1950.

(B) Articles on Geodetic Subjects.

1.	.. ..	The Indian Geoid and Gravity Anomalies, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. and Capt. G. Bomford, R.E. (Bulletin Géodésique, No. 29, Jan.–March 1931, pages 20, 21, Paris).
2.	.. ..	Construction of the Geoid, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. and Capt. G. Bomford, R.E. (Bulletin Géodésique, No. 29, Jan.–March 1931, pages 22–26, Paris).
3.	.. ..	*‡The Hypothesis of Isostasy, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (The Observatory, Dec. 1931 and Geophysical Supplement to Monthly Notices of the Royal Astronomical Society, January 1932).
4.	.. ..	†Stokes's Formula in Geodesy, by B. L. Gulatee, M.A. (Cantab.). (Nature, 20th Feb., 1932).
5.	.. ..	*"Crustal Warpings" discussing the gravity work of the Survey of India, by Maj. E. A. Glennie, D.S.O., R.E. (The Observatory January and April 1933).

* Obtainable from Messrs. Taylor and Francis, Red Lion Court, Fleet Street, London, W.C.

† Obtainable from the office of Nature, St. Martin's Street, London, W.C. 2.

‡ Obtainable from the Royal Astronomical Society, Burlington House, London, W. 1.

No.	Name of Book	Details
6.	.. ..	*Figure of the Earth, by B. L. Gulatee, M.A. (Cantab.), (Gerlands Beiträge, Bd. 38, H. 3/4, S.426, 1933).
7.	.. ..	†Deflection of the Plumb-Line, by B. L. Gulatee, M.A. (Cantab.), (Hydrographic Review, Vol. X, No. 2, Nov. 1933, pages 182–189).
8.	.. ..	*Isostasy in India, by Lt.-Colonel E. A. Glennie, D.S.O., R.E. (Gerlands Beiträge Zur Geophysik, Vol. 43, No. 4, 1935).
9.	.. ..	‡The Figure of the Earth from Gravity Observations and the Precision Obtainable, by J. de Graaff Hunter, C.I.E., SC.D. (Philosophical Transactions, Royal Society, Series A, Vol. 234, 1935).
10.	.. ..	§On the Subterranean Mass-Anomalies in India, by B. L. Gulatee, M.A. (Cantab.), (Proceedings of the Academy of Sciences, U. P. India, Vol. 5, Sept. 1935).
11.	.. ..	‖Crustal Warping in the United States, by Lt.-Col. E. A. Glennie, D.S.O., R.E. (Gerlands Beiträge Zur Geophysik, Vol. 46, pp. 193–197, 1936).
12.	.. ..	‖The Boundary Problems of Potential Theory & Geodesy, by B. L. Gulatee, M.A. (Cantab.), (Gerlands Beiträge Zur Geophysik, Vol. 46, pp. 91–98, 1936).
13.	.. ..	Geophysical Prospecting for Manganese, by B. L. Gulatee, M.A. (Cantab.), (Journal of Scientific and Industrial Research, Vol. III, No. 12, June 1945, pp. 543–554).
14.	.. ..	Standards of Length, by B. L. Gulatee, M.A. (Cantab.), (Journal of Scientific and Industrial Research, Vol. IV, No. 8, Feb. 1946, pp. 453–59).
15.	.. ..	Standards of Measurement, by B. L. Gulatee, M.A. (Cantab.), (Journal of Scientific and Industrial Research, Vol. V, No. 3, Sept. 1946, pp. 104–05).

* Obtainable from Akademische Verlagsgesellschaft M.B.H., Leipzig.

† Obtainable from the International Hydrographic Bureau, Monte-Carlo, Monaco.

‡ Obtainable from Messrs. Dulau & Co., 37 Soho Square, London, W. or Messrs. Harrison & Sons, St. Martin's Lane, Lnodon, or The Royal Society at Burlington House, London.

§ Obtainable from the Academy of Sciences, U.P., Allahabad.

‖ Obtainable from Akademische Verlagsgesellschaft M.B.H. Leipzig.

No.	*Name of Book*	*Details*
16.	.. ..	Angular Corrections for the Lambert Orthomorphic Conical Projection, by B. L. Gulatee, M.A. (Cantab.), (Empire Survey Review, Vol. VIII, No. 62, Oct. 1946, pp. 311–14).
17.	.. ..	Secular Variation of Magnetic Declination in India, by B. L. Gulatee, M.A. (Cantab.), (Science and Culture, Vol. XII, No. 5, Nov. 1946, pp. 215–17).
18.	.. ..	Future of Geophysics in India, by B. L. Gulatee, M.A. (Cantab.), (Journal of Scientific and Industrial Research, Vol. VI, No. 2, Feb. 1947, pp. 53–59 & 71).
19.	.. ..	The Hunter Shutter Eye-Piece for Longitude and Azimuth, by J. de Graaff Hunter, C.I.E., SC.D., F.R.S. (Empire Survey Review, Vol. IX, No. 63, Jan. 47, pp. 20–24).
20.	.. ..	Practical application of the Laplace Longitude—Azimuth relation to control of Geodetic Anomalies, by J. de Graaff Hunter, C.I.E., SC.D., F.R.S. (Empire Survey Review, Vol. IX, No. 65, July 1947, pp. 131–34).
21.	.. ..	The Level net of India and its datum, by B. L. Gulatee, M.A. (Cantab.), (Journal of the Central Board of Irrigation).

G. & T.C.—P.O.—J.S. 178—21-7-49—300 bks.

Chart XVIII


AVERAGE HEIGHT MAP OF INDIA
Revised and extended edition 1950.
Scale 1/5 Million or 1·014 Inches = 80 Miles = 128·746 Kilometres
Miles 100 50 0 100 200 300 Miles
Kilometres 100 50 0 100 200 300 400 500 Kilometres
Note:- Heights and depths are in feet.
QUETTA
LAHORE
LUCKNOW
KARACHI
JUBBULPORE
CALCUTTA
MANDALAY
BOMBAY
RANGOON
MADRAS
COLOMBO
SULAIMAN RANGE
INDUS BASIN
GREAT HIMALAYA MOUNTAINS
LADAKH RANGE
KAILAS RANGE
BRAHMAPUTRA BASIN
GANGES BASIN
ARAVALLI HILLS
VINDHYA MOUNTAINS
SATPURA HILLS
NARBADA BASIN
TAPTI BASIN
MAHANADI BASIN
GODAVARI BASIN
ARAKAN YOMA RANGE
IRRAWADDY BASIN
PENNER BASIN
EASTERN GHATS
ARABIAN SEA
BAY OF BENGAL