DR. JAMES DE GRAAFF HUNTER, SC.D., F.INST.P.
DIRECTOR GEODETIC BRANCH, SURVEY OF INDIA. 1928—32.

DR. JAMES DE GRAAFF HUNTER, M.A., SC.D., F.INST.P.

Dr. de Graaff Hunter, whose portrait faces this page, joined the Survey of India in 1907, as Mathematical expert, his designation being changed to Mathematical adviser in 1913. He was brought on to the cadre of the Class I Service in 1915, and was eventually promoted to be Director of the Geodetic Branch in 1928. Owing to drastic retrenchment in the expenditure of the Department, Dr. Hunter's service was brought to a premature close in November 1932, when he proceeded on long leave pending retirement.

Except for a period during the Great War, Dr. Hunter spent the whole of these 25 years in the Trigonometrical Survey, or Geodetic Branch, with headquarters at Dehra Dūn.

During 1908–09 he was employed on principal triangulation in Kashmīr, and in 1916–17 on the Madura and Bāgalkot Series in south India. From September 1917 to July 1919 he was on military service with the Mesopotamian Survey Party with the rank of Captain. He did much valuable triangulation, both in Irāq and in Persian Kurdistān, and was in charge of surveys in southern Kurdistān when the rebellion of May 1919 broke out.

Dr. Hunter's chief interests were connected with the observatory section and computing office at Dehra Dūn. Besides his outstanding mathematical genius he had a very sound and wide knowledge of physics, and a distinct mechanical skill, and he introduced many improvements into methods and instruments. He designed the original Hunter Short Base described in Departmental Paper No. 10. His researches into subjects affecting the figure of the earth have roused world-wide interest, and he has recorded and published his deductions in a valuable series of publications, lectures, and contributions to technical papers.

He is responsible for the production of the fifth edition of the Auxiliary Tables of the Survey of India, and of the Geodetic Reports of the Survey of India from 1922 to 1932.

Amongst his publications may be noted:

Gravity Survey	In Dictionary of Applied Physics Vol. II	
Trigonometrical Heights and Atmospheric Refraction	Do.	Do.
Geodesy	In 13th Edition of Encyclopædia Brittanica	
Atmospheric Refraction	Professional Paper No. 14, Survey of India	
The Earth's Axes and Triangulation	Professional Paper No. 16	,,
Geodesy	Departmental Paper No. 12	,,

In 1920 he was awarded the degree of Doctor of Science at Cambridge.

He represented the Survey of India at the International Union of Geodesy and Geophysics in 1922, and he presided at Section of Mathematics and Physics of the fifteenth Indian Science Congress at Calcutta in 1928.

Dr. Hunter's deep knowledge and sound judgment in all geodetic and geophysical branches of science will be seriously missed in the department.

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CONTENTS

CHAPTER I

Computations and Publication of data

CHAPTER II

Observatories

CHAPTER III

Tides

CHAPTER IV

Gravity

(i) FIELD SEASON 1931-32

(ii) RESEARCH WORK

CHAPTER V

Triangulation

Triangulation—(*Contd.*)

Charts and Plates

INTRODUCTION

1. The year 1931-32 has been heavily overshadowed by retrenchment and changes in organization. The Geodetic Branch, which latterly had consisted of 48 *per cent* geodetic units (Computing & Tidal Party and Nos. 14, 15 & 17 Parties) and 52 *per cent* non-geodetic units [No. 2 Drawing Office, Forest Map Office, No. 16 Party (Publication and Stores) and Training School],—the percentage being on the basis of expenditure—was reduced all round. It on the other hand, absorbed a topographical circle (Central Circle) less one party (No. 5) which was transferred to the Eastern Circle. The Geodetic Branch now consists of 36 *per cent* geodetic units (detailed in next paragraph) and 64 *per cent* non-geodetic units (No. 2 Drawing Office and Forest Map Office, No. 1 Party, No. 20 Detachment, Printing Office, Photo-Zinco Office and Workshops). These reductions and amalgamations started gradually from about December 1931, but did not very seriously affect the field units until their field programmes, curtailed in some instances, had been completed.

2. The new organization provides the following geodetic units:

(*a*) No. 14 Party (Geophysical) with 3 potential detachments:
  - (*i*) Pendulum.
  - (*ii*) Latitude and Longitude (deflection).
  - (*iii*) Gravity gradiometer.

(*b*) No. 15 Party (Triangulation and Levelling) with three sections:
  - (*i*) Triangulation and base-line.
  - (*ii*) Levelling.
  - (*iii*) Protection and Maintenance of stations and bench marks; Workshops and Stores.

(*c*) Computing and Tidal Party with the following sections:
  - (*i*) Computing Section.
  - (*ii*) Tidal Section (prediction and occasional analysis).
  - (*iii*) Observatory Section (Latitude, Longitude, Time, Magnetism, Meteorology, Seismology, and Standards of measurement).
  - (*iv*) Printing Office.
  - (*v*) Photo-Zinco Office.

The Geodetic units have been seriously cut down. It is fortunate that improvements in instruments and methods of observation have advanced rapidly in recent years, and admit of field results being obtained more rapidly than was formerly possible.

3. *Pendulum work.* (Chapter IV). An apt illustration of the last remark is provided by the gravity work, and great credit is due to Major E. A. Glennie, D.S.O., R.E., who has been in charge of these operations for a number of years. For the season 1931-32 the original programme was to determine gravity at stations in a belt extending nearly across India roughly on a line from Bombay to Calcutta. Access to much of the region by rail was impracticable and two 1½-ton motor trucks were employed with great success. Reductions in personnel were necessary. The conditions of roads in India made this form of transport quite a speculation, which was happily fully justified. In fact expectation was surpassed and Major Glennie was able to propose additional stations for observation. In all, 46 stations were occupied, bringing up the total number of departmental gravity stations in India and Burma to 273, (of which only 11 are in Burma). The field season extended from November 20th, 1931 to May 3rd, 1932; the unusually late date of termination being made possible by keeping the final month for observations in the hills, and was particularly desirable owing to Major Glennie's anticipated absence from India during the next field season.

In addition to improvements in the routine of observation which allowed so many stations to be occupied, methods of reduction of observations now enable this to be in an advanced stage when the party returns from the field. Major Glennie has also been able to develop further his ideas for the interpretation of gravity results in relation to the known geology, and to apply them to elucidation of crustal formations. Some of this work is set forth in Chapter IV, para 6; but in this connection his Professional Paper No. 27 (Gravity Anomalies and the Structure of the Earth's Crust), published in 1932, should be read. It is to be remarked that the conclusions are not in accord with the Hayford concept of isostasy.

At the end of para 12, Chapter IV, Major Glennie denies the "common but erroneous impressions" that the geoid tends to follow the surface configuration. I think he is correct. Any *additional* matter anywhere, of course, raises the potential everywhere and more particularly in the vicinity of extra matter: so that as a result the geoid would be higher there than if the extra matter were removed. But this does not show that the geoid is elevated at that point above the reference spheroid. It is possible to have a depressed geoid associated with either excess or defect of local gravity. Stokes' formula indicates the rise of geoid due to gravity anomalies, from which it is clear that anomalies all over the world affect the geoidal level.

4. *Triangulation.* (Chapter V). The Dālbandin Meridional Series along meridian 65° E. in Baluchistān, linking the Kalāt and Makrān series, was observed by Captain G. Bomford, R.E., with very satisfactory closure. The large Wild instrument was used and contributed to the rapid completion of the work in 9 weeks of observation. No night observations were made.

The series comprised some very long rays, one of which from Malik Surinda H.S. to Choto-i-jik H.S. is 80 miles long, and actually the longest ray of the Indian geodetic triangulation. The average triangular error was $0''\cdot71$, $m=0''\cdot47$ and $M=0''\cdot32$.

Astronomical observations were made at 7 stations for latitude and 5 stations for azimuth to extend our knowledge of the form of the geoid into Baluchistān. It is pleasant to be able to record that the Wild theodolite proved very convenient and expeditious for this work.

The geoidal contours resulting from these and other available deflections are discussed in para 9 and illustrated with reference to the International spheroid in Chart XV. The rise of the geoid above this spheroid is notably large and shows that the Survey of India spheroid, (derived from data available in 1923) fits this part of the geoid better than the International spheroid and that even the Survey of India spheroid has too large a value of the inverse of the ellipticity. In Kashmīr the superiority of the Survey of India spheroid was demonstrated previously.

Every effort is being made to extend the region in which the geoidal form is determinable: and in the coming field season (1932-33) a line of deflection observations (both components) is being carried from the eastern boundary of India across Burma to the Burmo-Siam borders. It is much to be hoped that this will be further extended by neighbouring surveys through Siam and Malaya, and subsequently through the Islands of the Dutch East Indies where thorough triangulation has been effected.

5. *Levelling.* (Chapter VI). Owing to need for economy no geodetic levelling was effected this season. It is regrettable that progress with the level net of high precision is thus arrested, and will remain so for the coming season too. It is however far better to close down work on this net until funds are available to make substantial progress, sufficient to close definite circuits in reasonable time, and thus avoid all chance of confusion by changes of level. In 1932-33 only one precision levelling detachment is taking the field: and this will connect the levelling systems of India and Burma. Junction with Siam is postponed till 1933-34.

6. *Geodetic Charts.* (Chapter I and Chapter VII, Sec. II). The interest in geodetic data increases greatly when the area covered is extended. It is accordingly of great importance to be aware of the possibilities of extensions. One should be acquainted with the

work of adjoining countries. With this object in view two charts have been produced. One is the *Index Chart of Geodetic Surveys in India and neighbouring countries* on the scale of 1/6 M. On this are shown all the operations of geodetic interest performed not only in India and Burma but also in the adjacent countries Siam, French Indo-China, Malaya, and Ceylon.

The second chart *Geodetic Surveys between India and Australia* is on the scale of 1/10 M (appx.) and primarily purports to illustrate the situation as regards geodetic triangulation. Enquiries were made from the following authorities :

(1) The Director of Commonwealth Lands and Surveys, Melbourne, Australia.

(2) Het Hoofd van den Topografischen Dienst, Batavia, Java.

(3) The Director, U. S. Coast and Geodetic Survey, Washington.

(4) The Surveyor General, Federated Malay States.

(5) The Commissioner of Lands, Sandakan, N. Borneo

and from their replies the chart has been compiled. A brief account of the situation is also given in Chapter VII, Sec. II by Mr. Gulatee. From these it will be seen that the Indian triangulation system is joined with Burma and Siam and French Indo-China, while the connection of Siam and Malaya can be made by a small amount of observing. Between Malaya and Sumatra triangulations there is a gap of some 180 miles. When these two gaps are filled triangulation will be continuous from the trijunction of Persia, Afghānistān and Baluchistān (λ 30° N., L. 61° E.) up to the Soenda Archipelago (λ 8° S., L. 117° E.).

In this chart are also shown the submarine pendulum observations of Dr. Vening Meinesz. These give an additional force to the necessity of completing the triangulation connections suggested above, which should be followed up by deflection observations, continuous from Burma.

7. *Tidal operations.* These are described by Mr. R. B. Mathur in Chapter III. They consist mostly of predictions, but analysis of observations (para 4) of the Orissa ports Chāndbāli and Shortt Island have been practically completed. Basrah predicitions (para 5) have not responded to ordinary treatment used for riverain ports, and it is thought that the relatively larger amplitude of the diurnal components contributes to this lack of success.

8. Mr. Mathur also reports (Chapter II) on the work of the observatories. Longitude observations have been made regularly by transit fitted with moving wire micrometer. The result suggests some residual personality between the two observers of such an order as $0''\cdot05$.

Clocks. The Riefler clock has worked well. The recently installed Shortt clock gave trouble owing to leakage in the vacuum chamber. This was finally corrected about August, but there is not sufficient experience of the running of the clock to justify any statement concerning it.

Latitude variation. Observations have also been continued with satisfactory accuracy. The amplitude of variation of latitude at Dehra appears to be considerably greater than that observed elsewhere. The idea occurred that this might be due to a seasonal change in tilt of the atmosphere's isopycnic surfaces. Enquiry from the Meteorological Department has resulted in intimation that the surfaces do tilt by a variable amount which qualitatively fit the suspected abnormalities, but quantitatively is only about 1/5th of what is required. It is possible however that these tilts are accentuated by the special topographic situation of Dehra Dūn.

9. *Research items.*

Longitude observation. Experiments have been made with a new plan of observation of time for longitude determination. The position of a star is read against a scale at definite instants, regulated by a shutter which is actuated by the clock. It is hoped that by this means personality will be avoided or much reduced. The experiments are not yet completed, but give considerable promise of success (see "Observatories" Chapter II, para 6).

Snow peaks. (Chapter VII, Sec. I). It has been a matter of interest to determine whether the Himālayas are still rising. About 25 years ago several series of observations of vertical angles to snow peaks in the Kumaun Himālaya were made and the height of the peaks were determined (*vide* Professional Paper No. 14). During March 1932 further observations were taken and these will be continued in 1933. The results so far obtained indicate that no considerable change in altitude has occurred in the last quarter of a century: the small changes in the height values deduced being within the likely errors to which the observations and their reduction are subject.

Isostasy. A paper on the "Hypothesis of Isostasy" by Dr. Hunter was read at the Geophysical Meeting, Royal Astronomical Society in October 1931. It has been reprinted in the Geophysical Supplement to the Monthly Notices of the Royal Astronomical Society.

Gravity and the Geoid. In 1849 an important paper by Sir G.G. Stokes was published. At that time the gravity data was scanty, but now although much remains to be done, the data available is much increased and there is prospect of useful application of Stokes' formulæ. The paper concerned is difficult of access, being out of print and for various reasons full use of it has not been made. I have accordingly thought it desirable to reproduce portions of the paper, so as to render it accessible to our geodetic workers. The extracts and comments have been made by Mr. B. L. Gulatee.

10. *Personnel.* The *personnel* of the Geodetic portion of the Geodetic Branch is given on pages xvi and xvii.

DEHRA DŪN,
November 1932.

J. DE GRAAFF HUNTER,
Director of the Geodetic Branch.

PERSONNEL* OF THE GEODETIC BRANCH, 1931-32.

Director, Geodetic Branch

LT.-COLONEL F. J. M. KING, R.E., to 20th Oct. 1931

DR. J. DE GRAAFF HUNTER, M.A., SC. D., F. INST. P., from 21st Oct. 1931

COMPUTING AND TIDAL PARTY

(RECORDS AND RESEARCH)

Class I Officers

Captain G. Bomford, R.E., in charge, to 26th Oct. 1931, from 1st Feb. 1932 to 22nd Feb. 1932 and from 25th May 1932 to 19th July 1932.

Dr. J. de Graaff Hunter, M.A., SC.D., F. INST. P., in charge from 27th Oct. 1931 to 31st Jan. 1932 and from 23rd Feb. 1932 to 28th Feb. 1932.

Lt.-Colonel A. H. Gwyn, I. A. in charge from 1st Mar. 1932 to 24th May 1932 and from 20th July 1932.

Mr. B. L. Gulatee, M.A. (Cantab.). Mathematical Adviser.

Class II Officers

Mr. M. N. A. Hashmie, B.A., to 21st Apr. 1932.

Lower Subordinate Service

1 Librarian.

4 Clerks.

COMPUTING SECTION

Upper Subordinate Service

Mr. R. C. Ray, 22nd Nov. 1931.

Mr. M. Chatterji.

Mr. S. Mitra to 6th Nov. 1931.

Mr. H. C. Deva, B.A.

Mr. T. N. Sharma, B.A. to 16th Nov. 1931.

Mr. A. K. Maitra, B.A.

Mr. R. K. Bhattacharya, B.A. to 11th Oct. 1931.

Mr. Sayed Irshad Ahmad, B.A. to 23rd Nov. 1931.

Mr. C. B. Madan, B.A.

Upper Subordinate Service—(contd.)

Mr. M. Das Gupta, B.SC. to 16th Nov. 1931.

Mr. J. N. Kohli from 1st Dec. 1931.

Lower Subordinate Service

14 Computers.

TIDAL SECTION

Class II Officers

Mr. R. B. Mathur, B.A., Tidal Assistant, to 25th Oct. 1931 and from 1st Feb. 1932.

Mr. D. H. Luxa, Tidal Assistant from 26th Oct. 1931 to 31st Jan. 1932.

Lower Subordinate Service

9 Computers.

OBSERVATORY SECTION

Upper Subordinate Service

Mr. H. C. Banerjea, B.A.

Mr. G. P. Rao, M.A.

Lower Subordinate Service

6 Computers.

MAGNETIC OBSERVATORY

Mr. Shyam Narain, B.SC.

DRAWING SECTION

(ADMINISTERED BY O.C. 2 D.O.)

Upper Subordinate Service

Mr. L. D. Joshi, to 10th July 1932.

Mr. A. A. S. Matlub Ahmad from 11th July 1932.

Lower Subordinate Service

6 Draftsmen.

14 PARTY (GEOPHYSICAL)

Class I Officers

Major E. A. Glennie, D.S.O., R.E., in charge to 24th June 1932.

Captain G. Bomford, R.E., in charge from 26th June 1932.

Lower Subordinate Service

2 Computers.

1 Clerk.

*** Excluding No. 2 Drawing and Forest Map Offices, Printing and Photo-Zinco Offices, No. 1 Party and 20 Detachments.**

15 PARTY (TRIANGULATION AND LEVELLING)

Class I Officers

Captain G. Bomford, R.E., in charge, to 22nd Feb. 1932.

* Lieut. I. H. R. Wilson, R.E., in charge 17 Party from 26th Oct. 1931 and 15 Party from 23rd Feb. 1932.

Class II Officers

* Mr. D. H. Luxa in charge 17 Party to 25th Oct. 1931.

Mr. N. N. Chukerbutty from 8th July 1932.

Mr. M. N. A. Hashmie, B.A., from 22nd Apr. 1932.

Upper Subordinate Service

* Mr. P. B. Roy to 15th Mar. 1932.

Upper Subordinate Service—(contd).

* Mr. A. A. S. Matlub Ahmad to 10th July 1932.

* Mr. J. N. Kohli from 21st Sep. 1932.

Mr. P. K. Chowdhury.

* Mr. I. D. Suri.

Mr. L. R. Howard.

* Mr. Mohd. Faizul Hasan.

* Mr. A. P. Dutta (Probationer).

* Mr. K. R. Gopalaiengar (Probationer) to 17th May 1932.

Lower Subordinate Service

15 Computers.

2 Clerks.

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* Officers of the late No. 17 Party which was in existence up to 29th Feb. 1932.

CHAPTER I

COMPUTATIONS AND PUBLICATION OF DATA

BY B. L. GULATEE, M.A.

1. Dalbandin Meridional Series. This series was observed by No. 15 Party in 1931-32, and links up the Kalāt Longitudinal and Makrān Longitudinal series which were lying pendant since a long time. The series starts from Kisanen Chappar—Pulchotau Hill Stations of the Kalāt Longitudinal series and closes on Kapar—Buzgalaband Hill Stations of the Makrān Longitudinal series. The series has been adjusted between its terminal sides and the closing errors have been dispersed. Details of closing errors are given in the chapter on Triangulation.

2. Mong Hsat Series. The revised Mong Hsat series has been adjusted between its terminal sides in Mandalay Meridional and Great Salween series. The closing errors are given on page 5, Table 2 of Geodetic Report Volume VII.

3. Mawkmai and old Mong Hsat Series. It has been realized that Mawkmai series (series No. 79 of the list of Geodetic series) and certain portions of the old Mong Hsat series which have not been effaced by the revised Mong Hsat series are not of geodetic character. They have consequently been adjusted graphically and will in future be treated as G.T. minor work.

4. Adjustment of minor triangulation. Satisfactory progress has been made with the adjustment of topographical triangulation in N.W. Frontier (see Geodetic Report Volume VII, page 7). The graphical adjustment of sheet I/M 39 and of Synoptical Volume I/A is now complete and that of I/M 34 is well in hand.

The minor triangulation in 92, I, J, K and Nepāl triangulation of 1924-26 have also been adjusted

5. Lambert Grid. The conversion of the co-ordinates of existing trigonometrical stations and points in N.W. Frontier has been continued steadily. About 8,000 points have so far been converted and 10,000 points classified in accordance with para 87(c), Chapter VIII, Handbook of Topography. The first Grid triangulation pamphlet has been compiled for sheet 38.O.

6. Publications. The stock of a 1,000 copies of "A sketch of the Geography and Geology of the Himālayan Mountains and Tibet", by Colonel S. G. Burrard and Mr. H. H. Hayden, which was issued in 1908 as a centenary review of the geographical knowledge that had been gained from 1807 to 1907, has been exhausted. The book proved invaluable as a work of reference for surveyors, and explorers, and there has been a steady public demand for it both in India and Europe and it has consequently been decided to bring out a revised edition. Sir Sidney Burrard has revised the geographical portions Parts I, II, III, in collaboration with the Geodetic Branch Office. Part IV, which forms the geological portion has been revised by Dr. A.M. Heron, of the Geological Survey of India. Parts I and II are now at press.

The triangulation data for 19 Indian and 1 Persian degree sheets have been compiled. 16 Persian pamphlets (19 degree sheets) have been printed. 3 Indian pamphlets have been reprinted.

Reprint of levelling pamphlet for sheet 40 has been made complete for the press. 260 miles of High Precision levelling and 300 miles of Precise levelling have been printed as addenda; 1 Secondary levelling pamphlet has been reproduced by Gestetner.

A start has been made with the compilation of Auxiliary Tables, Part VI, which will explain the various forms and formulæ in use in the Survey of India.

In addition to the above the following publications have been seen through the press:

(*a*) Geodetic Report Volume VII.

(*b*) Auxiliary Tables, Part V (Lambert Grid).

(*c*) Professional Paper No. 27 "Gravity Anomalies and the Structure of the Earth's Crust".

(*d*) Departmental Paper No. 14. "Instructions for use of the Wild Universal theodolite and the Wild Photo-theodolite".

(*e*) Geodetic Handbook, Part I, (Geodetic Triangulation: Section II, Computations).

(*f*) Part A (Triangulation Tables) of Auxiliary Tables, Part IV.

(*g*) Record Volume XXIII. "Report of Sind Rectangulation".

7. Miscellaneous Computations. The gridding of various special maps has necessitated the computation of many sets of grid cutting-points on meridians and parallels which had not been included in the regular tables.

Sir Aurel Stein's barometer, time and latitude observations made during his journey through E. Turkistān in 1931 were reduced. The method of reduction used is described in appendix to "Record Vol. XVII of Survey of India, Memoirs on Maps of Chinese

Turkistān and Kansu ". Leh was used as the base station and it was discovered that height 4,043 feet of Kāshgar adopted for the reduction of his previous observations of 1915 was in error, and accounted for the marked disagreement between the heights of stations which were common to his 1915 and 1931 journeys. An attempt was made to arrive at a more reliable figure for the height of Kāshgar and the following information was collected :

No.	SOURCE	SYSTEM	HEIGHT	POINT OF REFERENCE
1	Capt. Trotter ...	Hypsometric	4,043	Not defined in the records.
2	Sven Hedin ...	Barometric	4,278	British Consulate, Chīnī-bāgh.
3	3 Russian Maps (C. Clementi)	Not known	4,213	Do.
4	Abbeti ...	Barometric	4,406	Not defined.
5	Survey of India 1931 (Leh as base) ...	Barometric	4,453	British Consulate, Chīnī-bāgh.
6	Director General of Observatories ...	Not known	4,200	Do.

From the above no definite conclusion can be drawn, and for reduction a provisional value of 4,200 feet was accepted as the height of British Consulate, Chīnī-bāgh. This gave a much better accord between the stations common to 1915 and 1931 observations.

Deflections have been computed on Hayford system for 92 stations.

On requisition from Manager, Raipur Tea Estate for a sundial, tables were made for its construction.

8. Index Chart to Geodetic Surveys in India and neighbouring countries. The index chart on the 1/6M scale. (Chart XXI in pocket at end), showing Indian Geodetic triangulation and its connections with foreign triangulation, the Indian level net, latitude, longitude, azimuth, pendulum and tidal stations and all other information of geodetic interest, which was last issued in 1923 has been brought up to date with considerable additions.

9. Triangulation connection to Australia. A chart (Chart XXII in pocket at end) has been drawn showing triangulation from India and Burma through Malay Peninsula to the neighbouring Islands e. g. Java, Sumatra, Celebes and Phillipine Islands (see Chapter VII, Section II).

10. Geodetic triangulation and levelling in Malaya. A chart on the scale of 1 inch = 32 miles (Chart XVIII in Chapter VII, Section II) has also been prepared to show the geodetic triangulation and levelling in Malaya. The base-lines, astronomical latitude and azimuth stations and the contemplated junction between the Siamese and Malay triangulations have been clearly depicted.

11. Exploration Krab file. Progress has been made with the compilation of information for a Krab file on 1/M sheets, which will show all exploration and other survey work not published in the ordinary pamphlets.

12. Supply of data. On the amalgamation of the Central Circle with Geodetic Branch, the Central Circle records have been lodged in the Computing Office.

The number of requisitions for triangulation, traverse and levelling data have consequently greatly increased.

13. Chart Section. The chart section has completed the following work:

(*a*) Charts for 22 triangulation pamphlets.
(*b*) Chart for 1 levelling pamphlet.
(*c*) 17 charts and plates for Geodetic Report, Volume VII.
(*d*) 3 charts for Geodetic Report, Volume VIII.
(*e*) 10 charts for Professional Paper No. 27.
(*f*) 3 figures for Departmental Paper No. 14.
(*g*) About 40 miscellaneous charts and figures.

Chapter II

OBSERVATORIES

by R. B. Mathur, B. A.

1. Standards of length. The six 24-metre invar wires to be used in the measurement of bases in Burma during the field season of 1932-33, were measured on two different days in September against the 24-metre base, the base itself being standardized against the 4-metre invar bar before and after the comparison on each day. The wires will be remeasured after the close of the field season and there will then be available the records of their changes in length over a period of two years.

The fundamental nickel 1-metre and Silica 1-metre standards which were sent to the National Physical Laboratory, Teddington, for standardization were received back during the year. Their respective certificates show a decrease of 0·0044 mm. in the former since 1914, and practically no change in the latter since 1925.

2. Longitude. The record of the longitude of Dehra Dūn was maintained as in previous years, by bi-weekly observations, (weather permitting) for local time with the bent transit, combined with the reception of wireless time signals from Bordeaux and Rugby, or from both, as a rule during the day, but during the night whenever, owing to atmospherics or weak reception, the day receptions were not successful. The time observer was Mr. H. C. Banerjea from 1-10-31 to 31-1-32 and Mr. R. B. Mathur for the rest of the year. The Riefler clock was used as the standard for observations and receptions except for the period 15-1-32 to 29-4-32, when the Shortt clock was so used.

The resulting values of longitudes are given in Table 1 and the monthly mean values are as follows:

Observer		Bordeaux			Rugby		
		h	*m*	*s*	*h*	*m*	*s*
H. C. B.	September 1931	5	12	11·70	5	12	11·75
	October ,,			11·73			11·75
	November ,,			11·75			11·78
	December ,,			11·75			11·78
	January 1932			11·73			11·78
R. B. M.	February ,,			11·85			11·88
	March ,,			11·77			11·78
	April ,,			11·76			11·75
	May ,,			11·74			11·73
	June ,,			11·70			11·74
	July ,,			...			11·76
	August ,,			...			11·68
	September ,,			11·70			11·67

3. Clocks. The Riefler clock stopped once in October 1931 and again in January 1932. On the latter occasion it was opened and cleaned and has since worked satisfactorily. The cause of these stoppages is considered to be some particle of dirt on the driving mechanism.

The vacuum of the Shortt clock has been the source of much trouble, until the end of June and necessitated the frequent use of the air-pump; then on the dome and the base glass plate being opened, a leak was discovered in the valve and remedied. Prior to this, the vacuum held satisfactorily for a period of about 3½ months and the clock was used as the standard, but as soon as the pressure was increased for the purpose of taking rate observations with changed pressure, the leakage started again and could not be located and remedied until 28-6-32.

With a view to regulating the rate, the dome was once opened on 8-1-32 to change the weight on the pendulum tray.

There was a short stoppage of the slave pendulum on 1-8-32, due evidently to a fall in the current of the batteries which actuate the clocks. The weights on the tray of the slave pendulum were adjusted several times to control the hits and misses of the synchronizing tongue.

The error, rate, pressure and temperature of the two clocks for their respective periods of observations are given in Table 2. In the case of the Shortt clock readings in column 6 of this table are of the oil gauge, the clock being kept nearly in vacuum with a pressure of about 30 mm.

The unusually hot weather during the months of June and July necessitated artificial cooling for the clock rooms.

4. Latitude variation. Another cycle in the programme of this work was completed in January 1932; Tables 3 and 4 give the result of the observations. The final closing error of the groups is $+0''{\cdot}07$ and has been distributed amongst the groups as in the previous year to give the mean monthly values of latitude; the variation is larger this year although the same standard of accuracy has been maintained.

It is considered that Dehra Dūn owing to its topographical situation may be exposed to abnormal variations of refraction on account of a possible non-horizontality of the surfaces of equal air density. Should this view gain strength from meteorological records, it is proposed to transfer the work to some place in Southern India, which would be outside the Himālayan influence and where the layers of equal air density may be expected to be more nearly horizontal.

5. Seismograph and meteorological observations. The Omori seismograph was in operation throughout the year, and a list of the earthquakes recorded is given in Table 5. The three very great earthquakes were those in Japan, the Eastern Archipelago and Mexico, which occurred on 2-11-31, 14-5-32 and 3-6-32 respectively.

Meteorological observations were recorded at 8 and 17 hours until the end of December 1931, but afterwards as a measure of economy at 8 hours only.

6 Experimental and other miscellaneous work. Comparative transit observations were carried out by Messrs. Mathur and Banerjea for a period of about 3½ months, to discover personal difference, if any, with the impersonal micrometer of the bent transit. The results which are given in Table 6 show that there was on an average a difference of 0·05 seconds between the two observers and that this difference was more than doubled when stars were intersected by the observers between two wires instead of on the single wire on which intersections are usually taken. Neither of the observers had any previous experience with the two-wire method, and both still feel more confidence in the single wire for the observation of any moving object; the increase in the personal difference is probably due to this. The sign of the personal difference as given in Table 6 means that Mr. Banerjea judges the instant of an intersection to be a little later than Mr. Mathur would, in other words he is (comparatively speaking) farther behind the star.

To eliminate this class of personal difference, Dr. de Graaff Hunter has devised an apparatus consisting of an illuminated shutter, electromagnetically controlled by a relay which is actuated by the clock whose error is being determined. The opening of the shutter at every clock second enables the star to be seen alongside the scale fixed in the focal plane of the object-glass. The scale used is a special one imported from England and divided to 0·1 mm. The period of the opening is regulated so as not to exceed 0·07 of a second and the position of the star is estimated in scale division at every opening of the shutter. In practice an opening every second was found to be too quick for accurate work, and passages at every third opening were estimated. A series of a few nights' observations were taken by Dr. Hunter, Captain Bomford and Mr. Mathur and the results of these observations are given in Table 7. The results hardly suggest any systematic errors and give hopes that with a sufficiency of intersections and with the apparatus perfected, there is every likelihood of personal differences being eliminated by this method of observation.

There remains for decision the manner of illuminating the field of view and of matching with it the light reflected from the moving shutter, so as to minimize the sensation of movement and its distracting effect on the observer. This has led to the trial of several devices. Experiments with concentrated light thrown in sideways through the edge of the glass on which the scale lines are engraved, have shown that the divisions are thrown up clearly, well illuminated on a dark background. This is expected to obviate the difficulty caused by the light reflected from the shutter; tests are in progress.

Comparative observations with the astrolabe using the eye-and-ear method, and the transit with the impersonal micrometer, were taken simultaneously by Messrs. Mathur and Banerjea on four different nights, to ascertain whether any systematic difference exists between them, and whether the eye-and-ear method yields better results than the tappet method of recording the passages. The results which are given in Table 8, whilst not sufficient to explain the difference between the observers, as obtained with the impersonal micrometer alone as given in Table 6, are a sufficient indication that the eye-and-ear method may be superior to the tappet method; but more observations in this respect are needed.

In connection with the vertical observations to snow peaks from the Camel's Back h.s. in March 1932 by Mr. Hashmie (see chapter VII, section I), a series of vertical observations extending over about a month were taken at Shaw's refraction station by Computer Prem Narain using the Wild theodolite, whilst Mr. Mathur carried out a two nights' programme for latitude and longitude deflections at the Camel's Back h.s. in April 1932, using the big astrolabe and the portable wireless set. The clock used for reception and time observations was the S. & R. clock 238 of No. 14 Party (Geophysical).

The levels of No. 15 Party were tested and their standard tapes standardized before and after the field season.

Consequent on the amalgamation of the Central Circle with the Geodetic Branch, the duty of the storage, upkeep and re-issue of instruments for all the field units has devolved on this Section. 29 theodolites and 40 levels, besides several other minor instruments were received during the year under report. These were examined, repaired and adjusted before re-issue.

Four Hunter Short Bases (new model) were standardized and supplied to the Frontier Circle units.

A Fortin's mercurial barometer belonging to the Forest Research Institute was overhauled and refilled, and some barometers and thermometers were standardized for departmental use.

The motor attachment for the driving of the impersonal micrometer of the north transit was received at the end of July 1932 and will be affixed during the winter months, when the experimental work on the transit eye-piece illumination and shutter is completed.

7. Magnetic observations. Except for a slight change in the absolute observation of Declination and Horizontal force, the usual programme of magnetic observations combined with a continuous photographic record of declination, horizontal force and vertical force was carried out. The declination and H. F. observations were taken twice every week up to 22-7-31 and consisted of 1½ set on each occasion, but from that date onwards, only single sets of observations were taken three times a week. The only severe magnetic storm recorded during the year occurred on 29-10-31.

The three magnetographs have worked satisfactorily, except for a few stoppages for short periods, of the driving clock of the H. F. and Declination instruments.

The mean scale value for 1931 for an ordinate of 1/25-inch were:

Horizontal force ...	4·26 gammas up to August 4·22 gammas from September
Vertical force ...	9·78 to 10·43 gammas
Declination ...	1·03 minutes.

The mean temperature for the year was 27·0° C. with maximum and minimum values of 27·2° and 26·6° C., the temperature of reduction being 27·0° C. A considerable fall in the moment of magnet No. 17 has occurred since the temperature experiments of May and June 1931, when the values of log $\pi^2 K$ for magnets Nos. 17 and 5B, were also determined. In computing the values of the magnetic elements, use has been made of new correction tables derived from the values of α and β determined in the temperature experiments mentioned above.

The mean values of the magnetic elements at Dehra Dūn during 1931 were:

Declination ...	E. 1° 8′·6
Dip ...	N. 45° 35′·9
H. F. ...	0·33001 C. G. S.
V. F. ...	0·33698 C. G. S.

Table 9 shows the mean monthly values of the magnetic collimation, the distribution constants $P_{1\cdot 2}$ and $P_{2\cdot 3}$ the accepted values of log $(1 + P/r^2 + Q/r^4)^{-1}$ and values of m for Magnet No. 17.

Table 10 gives the mean monthly observed values of the declination and horizontal force base-lines.

Table 11 shows the mean monthly values of the elements for 1930 and 1931 and the annual changes for the period. Tables 12-15 give the mean monthly values of the magnetic elements and the hourly deviations deduced from them for the winter and summer months; whilst the classification of the magnetic character for all days of the year is given in Table 16.

TABLE 1. *Variation of Longitude of Dehra Dūn from accepted value, as determined from reception of wireless time signals from Bordeaux and Rugby, 1931-32.*

Date (Greenwich)	Observed value *minus* accepted value*		Date (Greenwich)	Observed value *minus* accepted value*	
	Bordeaux	Rugby	...	Bordeaux	Rugby
1931			1932		
	s	s		s	s
Sept. 14	− 0·17	− 0·13	Feb. 27	+ 0·09	+ 0·16
16	− 0·03	− 0·02	Mar. 2	+ 0·10	+ 0·08
18	− 0·05	− 0·01	5	+ 0·05	+ 0·03
22	...	+ 0·02	10	+ 0·07	+ 0·06
25	− 0·10	− 0·06	13	− 0·02	− 0·02
30	...	− 0·04	16	− 0·09	− 0·06
Oct. 1	− 0·03	0·00	20	− 0·06	− 0·05
5	− 0·01	0·00	23	− 0·10	− 0·05
8	− 0·05	− 0·04	26	− 0·13	− 0·12
12	− 0·14	− 0·12	31	− 0·03	+ 0·01
19	− 0·05	− 0·03	April 5	− 0·04	− 0·04
Nov. 10	- 0·07	− 0·03	6	...	...
13	...	− 0·06	11	...	...
17	− 0·03	+ 0·02	14	− 0·01	0·00
20	− 0·08	− 0·01	21	...	− 0·07
24	0·00	+ 0·01	27	− 0·04	...
27	− 0·02	0·00	May 2	...	...
Dec. 1	0·00	+ 0·01	3	...	− 0·08
4	− 0·08	− 0·06	6	− 0·05	− 0·12
7	+ 0·02	0·00	10	...	− 0·09
11	− 0·06	− 0·04	13	− 0·05	...
16	− 0·10	− 0·03	17	...	− 0·08
17	+ 0·02	− 0·02	21	...	− 0·06
22	− 0·09	− 0·02	26	...	+ 0·01
24	− 0·06	+ 0·01	30	...	− 0·01
27	...	+ 0·03	June 4	...	...
31	− 0·04	+ 0·04	8	...	...
1932					
Jan. 3	− 0·05	...	11	...	+ 0·02
7	− 0·05	+ 0·02	17	...	− 0·05
12	− 0·08	0·00			− 0·05
15	...	...	22	− 0·09	− 0·09
16	− 0·06	0·00	28	...	− 0·07
18	− 0·07	− 0·02	July 2	...	+ 0·02
21	− 0·06	− 0·01	6	...	− 0·01
27	− 0·07	− 0·04	12	...	− 0·05
28	− 0·08	− 0·03	18	...	− 0·01
Feb. 4	+ 0·07	+ 0·09	25	...	− 0·10
7	+ 0·06	+ 0·08	Aug. 4	...	− 0·13
12	+ 0·03	+ 0·08	9	...	− 0·16
		+ 0·06	27	...	− 0·04
16	0·00	+ 0·05	Sept. 4	...	− 0·10
20	+ 0·12	+ 0·12	11	...	− 0·16
24	...	+ 0·09	15	...	− 0·11
			19	− 0·09	− 0·12

* Accepted value of Longitude is $5^h\ 12^m\ 11^s{\cdot}79$ (as determined in 1926).

TABLE 2. *Error, rate, temperature and pressure of Riefler clock No. 450 and Shortt clock No. 34 by the bent transit instrument, at 20 hrs. Indian standard time, 1931-32.*

1	2	3	4	5	6	7	8
Date	Error	No. of Time stars		During preceding period			**REMARKS**
		North	South	Rate * per day	Pressure	Temperature	
1931	*m* *s*			*s*	mm.	C.	
Oct. 1	+1 05·12	5	6	+0·23	598	26·8°	Observations on Riefler from this date.
5	06·16	5	6	+0·26	598	26·7	
8	06·98	5	5	+0·28	598	26·7	
12	08·04	4	5	+0·27	598	26·6	
19	+1 09·70	5	5	+0·24	597	26·7	Riefler clock stopped on 23rd Oct. and was restarted on 8th Nov. when the pressure was reduced to 600 mm.
Nov. 10	−0 01·00	3	3	...	602	26·5	
13	00·77	3	3	+0·08	602	26·6	
17	00·58	5	6	+0·05	602	26·6	
20	00·32	5	5	+0·09	601	26·8	
24	00·22	5	5	+0·03	602	26·7	
27	00·17	5	6	+0·02	602	26·6	
Dec. 1	00·17	5	5	0·00	602	26·7	
4	00·17	5	5	0·00	602	26·6	
7	00·18	5	5	0·00	602	26·5	
11	00·19	5	5	0·00	602	26·6	
16	00·24	5	5	−0·01	602	26·7	
17	00·29	5	6	−0·05	602	26·7	
22	00·41	5	5	−0·02	602	26·7	
24	00·47	6	5	−0·03	602	26·7	
27	00·64	5	5	−0·06	602	26·7	
31	00·81	5	5	−0·04	602	26·7	
1932							
Jan. 3	00·97	5	5	−0·05	602	26·2	
7	01·01	5	5	−0·01	602	26·7	
12	−0 01·30	5	7	−0·06	602	26·7	
15	+0 09·20	5	5	...	19·5	26·6	Observations on Shortt clock from this date.
16	09·16	5	5	−0·04	20·0	26·8	
18	09·10	5	6	−0·03	21·0	25·9	
21	08·93	5	6	−0·06	21·2	26·3	
27	08·68	4	3	−0·04	25·0	26·7	From this date onwards the observations were with the intersection of double wires newly fixed.
28	08·53	3	4	−0·05	25·5	26·8	
Feb. 4	08·25	4	4	−0·04	28·2	26·6	
7	08·12	4	4	−0·04	30·5	26·6	
12	+0 07·90	4	4	−0·04	31·2	26·5	

* +ᵛᵉ rate = gaining, −ᵛᵉ rate = losing.

(Continued)

TABLE 2. *Error, rate, temperature and pressure of Riefler clock No. 450 and Shortt clock No. 34 by the bent transit instrument, at 20 hrs. Indian standard time, 1931-32—(contd.).*

1		2		3	4	5	6	7	8
Date		Error		No. of Time stars		During preceding period			REMARKS
				North	South	Rate* per day	Pressure	Temperature	
1932		*m*	*s*			*s*	mm.	C.	
Feb.	16	+0	07·79	4	4	−0·03	32·5	26·7°	
	20		07·57	4	4	−0·06	33·4	26·7	
	24		07·51	4	4	−0·02	34·0	26·6	
	27		07·38	3	5	−0·04	34·5	26·5	
Mar.	2		07·29	5	6	−0·02	35·0	26·6	Observations on single wire as well as between double wires.
	5		07·23	5	5	−0·02	35·8	26·6	
	10		06·98	5	5	−0·05	36·5	26·7	
	13		06·89	5	5	−0·03	36·8	26·6	
	16		06·74	4	4	−0·05	37·0	26·5	
	20		06·52	5	5	−0·06	37·5	26·7	
	23		06·33	5	5	−0·07	37·3	26·4	
	26		06·13	5	5	−0·07	37·8	26·5	
	31		05·65	5	5	−0·10	38·0	26·5	
Apr.	5		05·32	5	5	−0·07	38·2	26·4	Intersection on single wire.
	6		05·29	5	5	−0·03	38·5	26·5	
	11		04·85	5	3	−0·09	38·4	26·4	
	14		04·55	4	4	−0·10	38·6	26·6	
	21		03·94	5	5	−0·09	38·5	26·3	
	27	+0	03·36	3	5	−0·09	38·7	26·3	
May	2	−0	19·82	4	4	...	598	26·5	Observations on Riefler clock from this date.
	3		19·82	5	5	0·00	598	26·9	
	6		19·72	4	4	+0·03	598	26·8	
	10		19·69	2	2	+0·01	598	26·7	
	13		19·73	4	4	−0·01	598	26·7	
	17		19·66	4	4	+0·02	598	26·8	
	21		19·65	4	4	0·00	598	27·2	
	26		19·72	4	4	−0·01	601	28·3	
	30		19·91	3	4	−0·05	602	28·2	
June	4		20·02	5	5	−0·02	603	28·9	
	8		20·03	4	4	0·00	603	28·4	
	11		20·01	3	4	+0·01	601	27·5	
	17		19·96	4	4	+0·01	600	28·0	
	22		19·96	4	4	0·00	600	27·9	
	28		19·86	4	3	+0·02	600	27·7	
July	2		19·92	5	4	−0·02	601	28·3	
	6	−0	19·81	5	3	+0·03	602	28·7	

* +ve rate = gaining, −ve rate = losing.

(*Continued*)

TABLE 2. *Error, rate, temperature and pressure of Riefler clock No. 450 and Shortt clock No. 34 by the bent transit instrument, at 20 hrs. Indian standard time, 1931-32—(concld.).*

1	2	3	4	5	6	7	8
Date	Error	No. of Time stars		During preceding period			REMARKS
		North	South	Rate † per day	Pressure	Temperature	
1932	*m* *s*			*s*	mm.	C.	
July 12	−0 19·74	4	4	+0·01	602	28·5°	
18	19·66	5	3	+0·01	600	27·3	
25	19·43	4	3	+0·03	601	27·6	
Aug. 4	19·08	4	3	+0·04	600	27·3	
9	18·86	5	4	+0·04	600	27·2	
26	17·66	2	3	+0·07	600	27·0	
27	17·62	5	5	+0·04	599	26·5	
Sept. 4	16·91	5	5	+0·09	599	26·7	
11	16·22	4	4	+0·10	599	27·1	
15	15·88	4	4	+0·09	598	26·5	
19	−0 15·47	4	5	+0·10	598	26·4	

† +ve rate = gaining, −ve rate = losing.

TABLE 3. *Latitude variation*

Declination errors of groups

Groups	Right Ascension		Dates	Latitude by evening group *minus* morning
	Evening	Morning		
	h m *h m*	*h m* *h m*		″
I—II	8 18 to 10 09	12 22 to 14 50	20th Feb. '31 to 15th April '31	−0·30 ± ·03
II—III	12 22 to 14 50	16 00 to 18 04	21st April '31 to 23rd May '31	−0·02 ± ·04
III—IV	16 00 to 18 04	18 56 to 20 58	28th May '31 to 17th Aug. '31	+0·12 ± ·04
IV—V	18 56 to 20 58	22 11 to 1 04	17th Aug. '31 to 12th Oct. '31	+0·05 ± ·03
V—VI	22 11 to 1 04	3 04 to 5 14	23rd Oct. '31 to 4th Dec. '31	+0·16 ± ·05
VI— I	3 04 to 5 14	8 18 to 10 09	9th Dec. '31 to 30th Jan. '32	+0·06 ± ·04
			Closing error ...	+0·07

TABLE 4. *Latitude variation*

Preliminary Results

Month	Monthly mean Latitude	Residuals Monthly *minus* Annual
	° ′ ″	″
February 1931.	30 18 51·57	0·00
March „	51·43	−0·14
April „	51·29	−0·28
May „	51·07	−0·50
June „	51·22	−0·35
July „	51·25	−0·32
August „	51·19	−0·38
September „	51·59	+0·02
October „	52·13	+0·56
November „	52·06	+0·49
December „	52·06	+0·49
January 1932.	30 18 52·02	+0·45
	Annual mean 51·57	...

TABLE 5. *Earthquakes recorded at Dehra Dūn during 1931-32.*

No.	Date	Indian standard time					Intensity of record	Distance	REMARKS
		1st P. T.	2nd P. T.	Long wave	Maximum	Finish			
	1931	*h m s*	*h m s*	*h m s*	*h m*	*h m*		*miles*	
1	Oct. 3	16 08 20†	16 09 20	16 10 30	16 12	16 34	slight	400	
2	,, 4	0 58 20	1 09 10	1 21 50	1 36	5 40	moderate	6000	Solomon Islands 10° S., 161·4° E. (acc. to Kew).
3	,, 6	4 02 50	4 03 40	4 04 20	4 05	4 45	slight	300	
4	,, 10	6 02 50	6 13 40	6 26 10	6 40	9 33	slight	5800	
5	,, 10	22 34 10†	22 37 50	22 40 40†	22 41	23 06†	slight	1400	
6	,, 28	0 24 30	...	0 25 00	0 25	0 40	slight	100	
7	Nov. 2	15 41 40	15 49 00	15 57 20	15 59	17 37	very great	3600	Destructive in Japanese Islands of Kyushu and Shikoku.
8	,, 4	20 53 20	20 54 30†	20 55 20†	20 55	22 11	slight	400	Quetta, Baluchistān.
9	,, 5	17 54 40	17 57 50	18 01 20	18 03	18 53	slight	1400	Seismograph clock under repairs from 23rd to 30th Nov. 1931.
10	Dec. 18	15 27 10	15 33 50	15 44 40	15 50	16 37	slight	3600	
	1932								
11	Jan. 4	17 25 00	...	17 25 30	17 26	17 28	slight	100	
12	,, 9	16 03 30	16 13 10	16 24 50	16 26	17 02	slight	5200	
13	,, 29	19 22 20†	19 33 40	...	19 34	22 55	slight	6600	
14	Feb. 12	6 27 50†	6 36 20†	6 42 10	6 44	8 03	slight	3900	
15	Mar. 5	4 51 50	4 52 50	4 53 10	4 53	5 02	slight	300	
16	,, 26	5 40 40	5 50 50†	6 08 40†	6 14	7 29	slight	6300	
17	,, 26	15 32 20	15 40 40	15 55 20†	16 07	16 35	slight	5000	
18	,, 27	14 20 40	...	14 22 50†	14 23	14 38	slight	500	
19	,, 28	6 13 30	6 20 30	6 26 50†	6 28	6 55	slight	3200	
20	Apr. 18	16 56 20†	16 59 20†	17 02 30	17 03	17 19	slight	1200	
21	May 14	18 50 40	18 58 20	19 09 40	19 16	22 04	very great	4200	East Indian Archipelago. (acc. to Kew).
22	,, 21	15 59 00†	16 13 30	16 45 10†	16 50	17 55	slight	12000	Destructive in Central America 13° N., 88° W. (acc. to Kew).
23	,, 26	21 53 30†	22 00 40†	22 06 40†	22 17	23 39	slight	3300	
24	,, 28	7 59 40†	8 06 50†	8 16 00	8 18	8 42	slight	3700	
25	June 3	16 25 10	16 41 10†	17 03 20†	17 30	18 53	very great	9800	Destructive in Mexico 16° N., 104° W.
26	,, 18	16 01 50	...	...	16 05	...	slight	...	
27	,, 18	17 02 30	...	...	17 05	...	slight	...	
28	July 25	...	...	16 03 30	16 06	16 27	slight	...	
29	Aug. 12	...	...	9 40 20	9 46	10 12	slight	...	
30	,, 14	10 13 20	10 15 50	10 17 40	10 19	11 18	moderate	900	Felt in Assam.
31	Sept. 15	16 51 30†	16 58 30	17 05 40†	17 03	17 26	slight	3400	
32	,, 15	20 20 40†	20 30 00	20 38 00†	20 45	21 04	slight	4600	Destructive in New Zealand.
33	,, 23	20 00 20	20 07 00	20 12 30	20 13	20 45	slight	2900	
34	,, 27	0 59 10	1 05 50	1 12 10	1 25	2 24	slight	3100	Destructive in Macidonia, Balkan Peninsula.

† Recognized with difficulty.

TABLE 6. *Personal difference between observers with the impersonal micrometer.*

Date		Error (by R.B.M.)	Error (by H.C.B.)	Personal difference (R.B.M.—H.C.B.)
1931				
		m s	m s	s
Nov.	16	−0 0·70	−0 0·63†	−0·07
	17	·63†	·58	−0·05
	20	·42†	·32	−0·10
	22	·28	·27†	−0·01
	24	·23†	·22	−0·01
	26	·19	·19†	0·00
	27	·19†	·17	−0·02
	29	·20	·17†	−0·03
Dec.	1	·21†	·17	−0·04
	3	·23	·17†	−0·06
	4	·23†	·17	−0·06
	6	·24	·18†	−0·06
	7	·24†	·18	−0·06
	10	·22	·19†	−0·03
	11	·25†	·19	−0·06
	13	·30	·21†	−0·09
	16	·35†	·24	−0·11
	17	·36	·29	−0·07
	21	·41	·39†	−0·02
	22	·45†	·41	−0·04
	24	·54	·47	−0·07
	27	·70	·64	−0·06
	31	−0 0·86	−0 0·81	−0·05

Date		Error (by R.B.M.)	Error (by H.C.B.)	Personal difference (R.B.M.—H.C.B.)
1932				
		m s	m s	s
Jan.	3	−0 0·98	−0 0·97	−0·01
	7	1·03	1·01	−0·02
	12	1·34	1·30	−0·04
Observation on Shortt clock				
		m s	m s	s
Jan.	15	...	+0 9·20	...
	16	...	9·16	...
	18	+0 9·02	9·10	−0·08
	21	8·87†	8·93	−0·06
	27	8·58†	8·68*	−0·10
	28	8·53*	8·64†	−0·11
Feb.	4	8·25	8·34	−0·09
	7	8·12	8·25	−0·13
	12	7·90	7·99	−0·09
	16	7·79	7·91	−0·12
	20	7·57	7·73	−0·16
	24	7·51	7·64	−0·13
	27	+0 7·38	+0 7·49	−0·11
Mean from 16-11-31 to 21-1-32				−0·05
,, ,, 27-1-32 to 27-2-32				−0·12

* From 27th and 28th January 1932 observations made between two wires.

† Interpolated values.

TABLE 7. *Discrepancy between observers using the Shutter system of obscuring and opening the view of the star while transiting.*

Date		Number of stars and faces	Observers	Discrepancy in seconds of time
1932				
July	13	2 × 1	M—B	−0·03
	25	15 × 1	M—B	−0·07
Aug.	18	10 × 1	M—B	−0·08
	27	6¼ × 2	M—B	+0·12
Sept.	1	4 × 2	M—H	+0·05

TABLE 8. *Discrepancies in time error, as obtained by the eye-and-ear method of recording passages with the Astrolabe and the impersonal micrometer with the transit.*

1	2	3	4	5	6	7	8	9
Date	Error by Astrolabe			Error by transit		(3) – (6)	(4) – (6)	Mean of (7) & (8)
	Observer	P. V. Stars	Quadrant stars	Observer	Error			
1932		s	s		s	s	s	s
April 18	R.B.M.	+ 36·85	+ 36·70	H.C.B.	+ 36·61	+ 0·24	+ 0·09	+ 0·165
20	H.C.B.	51·98	51·68	R.B.M.	51·95	+ 0·03	– 0·27	– 0·120
21	R.B.M.	60·70	60·75	H.C.B.	60·64	+ 0·06	+ 0·11	+ 0·085
22	H.C.B.	+ 67·47	+ 67·33	R.B.M.	+ 67·37	+ 0·10	– 0·04	+ 0·030

TABLE 9. *Mean values of the constants of Magnet No. 17 in 1931.*

Month	Declination constants	H. F. constants				
		Distribution factors			Mean values of *m*	
	Mean magnetic collimation	$P_{1\cdot2}$	$P_{2\cdot3}$	Accepted value of $\log(1 + P/r^2 + Q/r^4)^{-1}$	Monthly mean	Accepted *m*
	′ ′	cm²	cm²		C.G.S.	C G S.
January ...	– 6 12	6·12	6·58	$\bar{1}\cdot99415$ throughout	807·03	807·03
February ...	– 6 14	6·32	6·49		6·96	6·96
March ...	– 6 14	5·91	6·84		7·14	7·14
April ...	– 6 17	5·78	6·27		7·29	7·29
May ...	– 6 17	5·80	8·16		*a* 7·27 *b* 5·23	7·27 5·23
June ...	– 6 10	5·84	6·65		*c* 4·03 *d* 2·17	4·03 2·17
July ...	– 6 13	6·08	6·48		2·15	2·15
August ...	– 6 18	6·17	7·17		2·09	2·09
September	– 6 14	6·17	7·53		1·56	1·56
October ...	– 5 56	6·16	7·55		1·63	1·63
November	– 6 05	6·33	7·26		1·51	1·51
December	– 6 05	6·36	6·91		801·40	801·40

a up to 20th *c* up to 9th
b from 21st *d* from 10th

TABLE 10. *Base-line values of Magnetographs at Dehra Dūn in 1931 from Magnet No. 17.*

Month		Declination	Horizontal force
		Mean value of base-line	Mean value of base-line
		° ′	C. G. S.
January	...	0 27·0	0·32661 [a] 764 [b]
February	...	27·2	761
March	...	27·5	759
April	...	27·9	774
May	...	27·2	782 [c] 781 [d]
June	...	27·6	782 [e] 776 [f]
July	...	28·3	787
August	...	28·0	779
September	...	28·5	772
October	...	28·1	783
November	...	28·3	774
December	...	0 28·3	0·32776

[a] Up to 10^h on 13th.

[b] From 11^h on 13th.

[c] Up to 10^h on 20th.

[d] From 11^h on 20th.

[e] Up to 10^h on 10th.

[f] From 11^h on 10th.

N. B. The above values have been accepted.

TABLE 11. *Monthly mean values of the Magnetic elements and their annual changes, Dehra Dūn, 1930 and 1931.*

MONTH	Horizontal force 0·32000 C. G. S. +			Declination E. 1° +			Dip N. 45° +			Vertical force 0·33000 C.G.S. +		
	1930	1931	Annual change	1930	1931	Annual change	1930	1931	Annual change	1930	1931	Annual change
	γ	γ	γ	′	′	′	′	′	′	γ	γ	γ
January	952	974	+ 22	13·6	10·0	− 3·6	32·8	35·5	+ 2·7	586	662	+ 76
February	958	978	+ 20	12·9	9·8	− 3·1	33·7	35·4	+ 1·7	610	664	+ 54
March	963	981	+ 18	12·5	9·7	− 2·8	33·3	35·3	+ 2·0	608	665	+ 57
April	954	1003	+ 49	12·5	9·7	− 2·8	34·9	34·7	− 0·2	630	676	+ 46
May	963	1009	+ 46	11·9	8·3	− 3·6	34·3	34·3	0·0	627	674	+ 47
June	964	1016	+ 52	11·6	8·4	− 3·2	34·4	35·0	+ 0·6	630	694	+ 64
July	962	1027	+ 65	12·1	8·3	− 3·8	34·3	35·5	+ 1·2	626	715	+ 89
August	972	1008	+ 36	11·6	7·9	− 3·7	34·7	36·4	+ 1·7	644	714	+ 70
September	957	1006	+ 49	11·5	8·3	− 3·2	34·5	36·8	+ 2·3	625	722	+ 97
October	956	1007	+ 51	11·5	7·5	− 4·0	36·3	37·1	+ 0·8	659	727	+ 68
November	976	996	+ 20	10·9	7·8	− 3·1	35·5	37·4	+ 1·9	664	723	+ 59
December	973	1012	+ 39	10·3	7·4	− 2·9	35·5	37·4	+ 1·9	662	738	+ 76
Mean	963	1001	+ 39	11·9	8·6	− 3·3	34·5	35·9	+ 1·4	631	698	+ 67

γ = 0·00001 C. G. S.

TABLE 12. *Declination at Dehra Dūn in 1931* (determined from five selected quiet days in each month).

Month	Monthly mean values *	Hourly deviation from the mean																							
		Mid.	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	Mid.
	E. 1°+ ′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
January ...	10·0	+0·4	+0·3	+0·4	+0·1	−0·3	−0·4	−0·6	−0·3	+0·3	**+0·8**	+0·7	−0·2	**−0·8**	−0·7	−0·6	−0·3	0·0	+0·3	+0·1	+0·1	+0·1	+0·3	+0·1	+0·2	+0·1
February ...	9·8	+0·2	+0·2	+0·3	−0·1	0·0	−0·1	0·0	−0·1	+0·4	**+1·1**	+1·1	+0·2	−0·9	**−1·4**	−1·3	−0·6	−0·1	0·0	+0·1	+0·1	+0·1	+0·1	0·0	+0·2	+0·3
March ...	9·7	0·0	0·0	0·0	0·0	−0·1	0·0	+0·1	+1·1	+2·5	**+3·0**	+2·1	−0·2	−1·8	**−2·5**	−2·3	−1·7	−0·5	+0·2	0·0	−0·3	−0·4	−0·3	−0·1	0·0	0·0
October ...	7·5	+0·7	+0·4	+0·6	+0·1	+0·1	+0·1	+0·2	+1·0	**+1·7**	+1·2	+0·2	−1·1	**−1·8**	−1·8	−1·1	−0·1	+0·4	+0·2	−0·2	−0·1	0·0	+0·1	+0·2	+0·4	+0·5
November ...	7·8	+0·4	+0·2	−0·1	−0·1	−0·5	−0·4	−0·4	0·0	+0·3	**+0·8**	+0·3	−0·7	−0·1	**−0·8**	0·0	+0·5	+0·7	+0·5	+0·2	+0·1	−0·2	0·0	+0·2	+0·4	+0·4
December ...	7·4	+0·1	+0·1	+0·2	0·0	−0·1	−0·4	−0·2	**−0·8**	−0·7	−0·1	0·0	−0·5	−0·7	−0·2	+0·3	**+0·5**	+0·5	+0·2	+0·1	0·0	+0·2	+0·1	+0·2	+0·2	+0·2
Winter Means ...	8·7	+0·3	+0·2	+0·2	0·0	−0·2	−0·2	−0·2	+0·2	+0·8	**+1·1**	+0·7	−0·4	−1·0	**−1·2**	−0·8	−0·3	+0·2	+0·2	+0·1	0·0	0·0	+0·1	+0·1	+0·2	+0·3
April ...	9·7	−0·2	−0·1	0·0	−0·1	−0·1	+0·1	+0·9	+1·9	+3·3	**+3·6**	+2·3	−0·6	−2·5	**−3·2**	−2·9	−2·0	−1·0	−0·3	−0·3	−0·4	−0·2	0·0	+0·2	+0·3	+0·6
May ...	8·3	+0·4	+0·2	+0·5	+0·5	+0·5	+0·6	+1·8	+2·8	**+3·3**	+2·4	+0·4	−2·1	−3·0	**−3·3**	−2·8	−2·0	−0·8	0·0	+0·2	0·0	0·0	+0·1	+0·1	+0·2	+0·3
June ...	8·4	+0·1	+0·2	+0·4	+0·4	+0·4	+0·6	+2·2	+3·1	**+3·2**	+2·5	+0·8	−1·3	−2·5	**−2·9**	−2·9	−2·3	−1·5	−0·6	−0·2	−0·3	−0·3	−0·1	−0·1	+0·1	+0·2
July ...	8·3	+0·3	+0·5	+0·6	+0·6	+0·7	+0·9	+2·0	+2·7	**+2·8**	+2·2	+0·7	−1·1	−2·3	−2·6	**−2·8**	−2·4	−1·4	−0·2	+0·2	0·0	−0·3	−0·2	−0·2	0·0	+0·2
August ...	7·9	+0·4	+0·3	+0·3	+0·6	+0·5	+0·5	+1·4	+2·3	**+2·8**	+2·3	+0·6	−1·5	−2·4	**−2·8**	−2·5	−1·5	−0·5	+0·1	+0·3	0·0	−0·1	−0·2	−0·5	−0·3	+0·1
September ...	8·3	+0·2	+0·4	+0·7	+0·6	+0·6	+0·8	+1·3	**+2·0**	+2·0	+1·2	−0·3	−1·8	−2·4	**−2·5**	−1·8	−0·9	+0·4	+0·3	+0·2	0·0	0·0	−0·2	−0·2	0·0	+0·3
Summer Means ...	8·5	+0·2	+0·3	+0·4	+0·4	+0·4	+0·6	+1·6	+2·5	**+2·9**	+2·4	+0·8	−1·4	−2·5	**−2·9**	−2·6	−1·9	−0·8	−0·1	+0·1	−0·1	−0·2	−0·1	−0·1	+0·1	+0·3

* Obtained from the mean of all hours for the five selected quiet days in each month.

NOTE. The mean declination for any hour in a month may be obtained by applying the hourly deviation for that hour with the sign given, to the monthly mean.
Figures in thick type indicate the maximum and minimum values of the hourly deviation.

TABLE 13. *Horizontal force at Dehra Dūn in 1931* (determined from five selected quiet days in each month).

Month	Monthly mean values *	Hourly deviation from the mean																								
		Mid.	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	Mid.
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
January ...	32974	− 5	− 5	**− 8**	− 6	− 3	− 3	+ 1	**+ 4**	**+ 4**	+ 2	0	+ 2	+ 3	+ 1	+ 2	+ 3	0	+ 2	+ 4	+ 2	− 1	− 2	− 4	− 2	+ 2
February ...	32978	**− 7**	− 6	− 6	− 3	− 5	− 5	− 4	− 3	+ 4	+ 2	+ 6	+12	**+13**	+12	+ 9	+ 8	+ 4	0	− 1	− 3	− 5	− 5	− 4	− 5	− 2
March ...	32981	+ 1	+ 1	+ 2	+ 2	+ 1	0	− 2	− 2	**− 5**	− 5	− 1	+ 3	+ 6	**+ 8**	+ 8	+ 5	− 1	− 4	− 3	− 2	0	0	− 1	− 1	− 1
October ...	33007	− 1	0	0	+ 3	+ 2	0	0	0	**− 5**	− 3	+ 3	+ 7	**+ 8**	+ 3	+ 2	+ 1	+ 1	− 5	− 3	− 5	− 4	− 1	+ 3	0	+ 1
November ...	32996	− 5	− 6	− 4	− 4	− 2	− 2	0	+ 2	+ 5	+ 8	+12	+16	**+18**	+14	+ 3	− 3	− 8	− 9	− 5	**−10**	− 8	− 5	− 2	− 5	− 2
December ...	33012	− 5	− 5	**− 6**	− 5	− 4	− 3	0	+ 4	+ 6	+ 9	+ 9	**+12**	+10	+ 9	+ 6	+ 4	− 1	− 5	− 4	− 5	− 4	− 6	− 6	− 5	− 5
Winter Means ...	32991	**− 4**	− 4	− 4	− 2	− 2	− 2	− 1	+ 1	+ 2	+ 2	+ 5	+ 9	**+10**	+ 8	+ 5	+ 3	− 1	− 4	− 2	− 4	− 4	− 3	− 2	− 3	− 1
April ...	33003	− 1	0	− 2	− 2	0	+ 2	− 1	− 4	− 7	− 7	− 1	+ 7	+12	+16	**+17**	+10	+ 6	0	− 3	− 5	− 7	− 8	− 8	**− 9**	− 8
May ...	009	− 6	− 6	− 5	− 4	− 3	− 3	− 2	− 4	− 7	− 4	+ 1	+11	+17	**+19**	+16	+10	+ 2	− 6	**− 8**	− 7	− 5	− 4	− 2	− 3	− 2
June ...	016	− 2	− 1	− 3	− 2	− 4	− 1	− 1	− 2	0	+ 2	+ 5	**+ 8**	+ 8	+ 8	+ 7	+ 4	− 2	− 6	**− 7**	− 7	− 4	− 5	− 4	− 2	− 3
July ...	027	− 3	− 4	− 3	− 3	− 3	0	+ 1	− 3	**− 5**	− 5	− 2	+ 5	**+11**	+10	+ 8	+ 5	+ 1	− 3	− 4	− 5	− 4	− 3	− 1	0	+ 1
August ...	008	− 5	− 2	− 2	− 4	− 2	− 2	− 1	− 4	−11	**−12**	− 8	− 1	+ 6	+14	**+17**	+14	+ 7	+ 4	− 1	− 1	− 2	− 3	+ 2	+ 3	+ 3
September ...	006	+ 1	0	0	0	+ 1	0	0	− 3	− 9	**−11**	− 8	− 4	+ 2	**+ 7**	+ 6	+ 4	− 2	+ 5	+ 4	− 2	+ 1	+ 2	+ 3	+ 4	+ 4
Summer Means ...	33012	− 3	− 2	− 3	− 3	− 2	− 1	− 1	− 3	**− 7**	− 6	− 2	+ 4	+ 9	**+12**	**+12**	+ 8	+ 2	− 1	− 3	− 5	− 4	− 4	− 2	− 1	− 1

γ = 0·00001 C. G. S.

* Obtained from the mean of all hours for the five selected quiet days in each month.

NOTE. The mean horizontal force for any hour in a month may be obtained by applying the hourly deviation for that hour with the sign given, to the monthly mean. Figures in thick type indicate the maximum and minimum values of the hourly deviation.

TABLE 14. *Vertical force at Dehra Dūn in 1931* (determined from five selected quiet days in each month).

Month	Monthly mean values *	Hourly deviation from the mean																							
		Mid.	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	Mid.
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
January ...	33662	− 1	− 1	− 1	− 1	0	0	0	0	+ 1	0	**− 4**	− 4	− 1	0	+ 1	**+ 3**	+ 3	+ 3	+ 2	+ 2	+ 1	+ 1	+ 1	+ 1	+ 3
February ...	664	− 1	− 2	− 3	− 3	− 5	− 5	− 4	− 5	− 3	− 5	**− 6**	− 4	− 6	− 3	0	+ 3	+ 3	+ 3	+ 4	+ 5	+ 6	+ 7	+ 8	+ 8	**+ 9**
March ...	665	+ 1	0	0	0	− 1	0	+ 1	+ 5	+ 5	− 1	−12	**−17**	−16	−12	− 5	0	+ 4	+ 5	+ 6	+ 6	+ 7	+ 7	+ 7	+ 7	**+ 8**
October ...	727	+ 2	+ 2	+ 2	+ 2	+ 2	+ 1	+ 2	**+ 5**	+ 2	− 3	− 7	−10	**−11**	− 8	0	+ 3	+ 4	+ 1	+ 2	+ 2	+ 2	+ 2	+ 3	+ 2	+ 2
November ...	723	+ 2	+ 2	+ 2	+ 1	+ 1	+ 1	+ 1	**+ 3**	+ 3	0	**− 6**	− 6	− 4	− 2	− 2	− 2	− 2	− 1	+ 1	− 1	0	+ 1	− 2	− 1	0
December ...	738	− 1	− 2	− 2	− 2	− 2	− 3	− 4	− 3	− 2	− 2	**− 5**	− 1	+ 4	**+ 6**	+ 6	+ 5	+ 1	0	+ 1	+ 1	0	− 1	− 1	− 1	− 2
Winter Means ...	33697	0	0	0	− 1	− 1	− 1	− 1	+ 1	+ 1	− 2	**− 7**	− 7	− 6	− 3	0	+ 2	+ 2	+ 2	**+ 3**	+ 3	+ 3	+ 3	+ 3	+ 3	+ 3
April ...	33676	+ 8	+ 8	+ 8	+ 9	+ 9	+10	+10	**+13**	+13	+ 8	− 2	−15	**−16**	−14	−10	− 7	− 4	− 3	− 3	− 3	− 2	− 2	− 1	− 1	− 1
May ...	674	+ 3	+ 3	+ 3	+ 3	+ 4	+ 5	+ 6	**+ 8**	+ 1	− 6	**−10**	−10	− 6	− 3	− 1	+ 2	+ 3	+ 2	+ 1	+ 1	+ 2	+ 2	+ 2	+ 3	+ 2
June ...	694	+ 3	+ 4	+ 3	+ 3	+ 4	+ 6	+ 8	+ 7	0	−10	−16	**−19**	−19	−15	− 7	0	+ 3	+ 8	+ 8	+ 7	+ 8	**+ 9**	+ 9	+ 8	+ 8
July ...	715	+ 1	+ 1	+ 1	+ 1	+ 1	+ 3	+ 5	+ 4	+ 1	− 4	−11	**−13**	−12	−11	− 8	− 2	+ 2	+ 5	+ 5	+ 4	+ 5	+ 6	**+ 7**	+ 7	+ 7
August ...	714	+ 4	+ 4	+ 4	+ 2	+ 4	+ 4	+ 6	**+ 8**	+ 5	− 2	− 7	−15	**−17**	−13	− 8	− 1	0	+ 3	+ 1	+ 1	+ 2	+ 3	+ 4	+ 4	+ 5
September ...	722	0	0	− 1	− 1	0	− 1	+ 2	+ 3	0	− 5	− 9	**−12**	− 9	− 5	− 3	+ 1	+ 2	+ 4	+ 2	+ 3	+ 4	**+ 5**	+ 4	+ 4	+ 4
Summer Means ...	33699	+ 3	+ 3	+ 3	+ 3	+ 4	+ 5	+ 6	**+ 7**	+ 3	− 3	− 9	**−14**	−13	−10	− 6	− 1	+ 1	+ 3	+ 2	+ 2	+ 3	+ 4	+ 4	+ 4	+ 4

γ = 0·00001 C.G.S.

* Obtained from the mean of all hours for the five selected quiet days in each month.

NOTE. The mean vertical force for any hour in a month may be obtained by applying the hourly deviation for that hour with the sign given, to the monthly mean.
Figures in thick type indicate the maximum and minimum values of the hourly deviation.

TABLE 15. *Dip at Dehra Dūn in 1931* (determined from five selected quiet days in each month).

Month	Monthly mean values *	Hourly deviation from the mean																								
		Mid.	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	Mid.
	N. 45° + ′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
January ...	35·5	+ 0·2	+0·2	**+0·4**	+0·3	+0·2	+0·2	0·0	−0·2	−0·2	−0·1	−0·2	**−0·3**	−0·2	0·0	−0·1	0·0	+0·2	0·0	−0·1	0·0	+0·1	+0·1	+0·2	+0·1	0·0
February ...	35·4	+ 0·3	+0·2	+0·1	0·0	0·0	0·0	0·0	−0·1	−0·4	−0·4	−0·6	−0·8	**−1·0**	−0·8	−0·4	−0·3	−0·1	+0·1	+0·3	+0·4	+0·5	+0·6	+0·6	**+0·7**	+0·5
March ...	35·3	0·0	−0·1	−0·1	−0·1	−0·1	0·0	+0·1	+0·3	**+0·5**	+0·2	−0·6	−1·0	**−1·1**	−1·1	−0·7	−0·3	+0·2	+0·4	+0·5	+0·4	+0·4	+0·4	+0·4	+0·4	+0·4
October ...	37·1	+ 0·1	+0·1	+0·1	−0·1	0·0	0·0	+0·1	+0·2	**+0·3**	0·0	−0·5	−0·9	**−1·0**	−0·6	−0·1	+0·1	+0·1	+0·3	+0·2	+0·3	+0·3	+0·1	0·0	+0·1	0·0
November ...	37·4	+ 0·4	**+0·5**	+0·4	+0·5	+0·2	+0·2	+0·1	+0·1	−0·1	−0·3	−0·9	**−1·1**	−1·1	−0·8	−0·2	+0·1	+0·4	+0·5	+0·4	+0·5	+0·5	+0·4	0·0	+0·2	+0·2
December ...	37·4	+ 0·2	+0·1	+0·2	+0·1	+0·1	0·0	−0·2	−0·3	−0·4	−0·6	**−0·7**	−0·7	−0·3	−0·2	0·0	0·0	+0·1	+0·2	+0·2	**+0·3**	+0·2	+0·3	+0·3	+0·2	+0·1
Winter Means ...	36·3	+ 0·2	+0·2	+0·2	+0·1	+0·1	+0·1	0·0	0·0	−0·1	−0·2	−0·6	**−0·8**	−0·8	−0·6	−0·3	−0·1	+0·2	**+0·3**	+0·2	+0·3	+0·3	+0·3	+0·3	+0·3	+0·2
April ...	34·7	+ 0·5	+0·4	+0·5	+0·6	+0·5	+0·4	+0·6	+0·9	**+1·0**	+0·8	−0·1	−1·1	−1·4	**−1·5**	−1·4	−0·9	−0·5	−0·1	0·0	+0·1	+0·3	+0·3	+0·4	+0·4	+0·4
May ...	34·3	+ 0·5	+0·5	+0·4	+0·3	+0·4	+0·4	+0·4	**+0·6**	+0·4	−0·1	−0·6	−1·1	**−1·2**	−1·1	−0·9	−0·4	0·0	+0·4	+0·5	+0·4	+0·3	+0·3	+0·2	+0·3	+0·2
June ...	35·0	+ 0·2	+0·2	+0·2	+0·2	+0·3	+0·3	+0·4	+0·4	0·0	−0·7	−1·1	**−1·4**	−1·4	−1·2	−0·8	−0·3	+0·2	**+0·7**	+0·7	+0·7	+0·6	+0·7	+0·6	+0·5	+0·5
July ...	35·5	+ 0·2	+0·2	+0·2	+0·2	+0·2	+0·1	+0·2	+0·3	+0·3	0·0	−0·5	−0·9	**−1·2**	−1·1	−0·9	−0·4	0·0	**+0·4**	+0·4	+0·4	+0·4	+0·4	+0·3	+0·3	+0·2
August ...	36·4	+ 0·5	+0·3	+0·3	+0·3	+0·3	+0·3	+0·3	+0·6	**+0·8**	+0·5	+0·1	− 0·7	−1·2	**−1·4**	− 1·3	−0·8	−0·4	−0·1	+0·1	+0·1	+0·2	+0·3	+0·1	0·0	+0·1
September ...	36·8	0·0	+0·1	+0·1	+0·1	0·0	+0·1	+0·2	+0·4	**+0·6**	+0·4	+0·1	−0·3	−0·5	−0·5	−0·4	−0·1	**−0·7**	0·0	0·0	+0·3	+0·2	+0·3	+0·1	+0·1	+0·1
Summer Means ...	35·5	+ 0·3	+0·4	+0·3	+0·3	+0·3	+0·3	+0·4	**+0·5**	+0·5	+0·2	−0·4	−0·9	**−1·2**	−1·1	−1·0	−0·5	−0·2	+0·2	+0·3	+0·3	+0·3	+0·4	+0·3	+0·3	+0·3

* Obtained from the mean of all hours for the five selected quiet days in each month.

NOTE. The mean dip for any hour in a month may be obtained by applying the hourly deviation for that hour with the sign given, to the monthly mean.
Figures in thick type indicate the maximum and minimum values of the hourly deviation.

Dehra Dun { Lat. 30° 19′ 19″ N. / Long. 78° 03′ 19″ E. } TABLE 16. *Classification and dates of Magnetic disturbances at Dehra Dūn in 1931.*

Dates	January	February	March	April	May	June	July	August	September	October	November	December
1931												
1	C	C	C	(C)	C	S	(C)	C	C	M	(C)	C
2	C	S	C	C	S	M	S	C	(C)	G	C	S
3	(C)	(C)	S	C	C	C	S	S	M	S	C	S
4	(C)	C	C	S	C	(C)	C	C	M	C	S	M
5	C	C	C	C	(C)	(C)	C	C	C	M	S	S
6	C	C	(C)	C	M	C	C	(C)	S	C	S	C
7	C	C	(C)	C	M	C	C	S	S	C	S	(C)
8	C	C	S	C	C	C	C	S	C	(C)	S	C
9	S	C	S	C	(C)	S	(C)	M	S	(C)	S	(C)
10	M	(C)	S	S	(C)	C	C	C	S	C	S	S
11	C	C	C	S	C	S	S	C	(C)	(C)	(C)	S
12	(C)	(C)	C	C	S	S	S	C	(C)	S	(C)	S
13	C	M	S	(C)	S	C	C	(C)	C	S	S	S
14	C	M	S	(C)	S	C	C	C	C	S	S	C
15	S	S	C	C	M	C	S	(C)	M	C	S	C
16	M	C	(C)	C	S	C	C	S	S	C	S	C
17	G	C	(C)	S	C	C	C	C	S	S	C	C
18	M	C	C	(C)	C	(C)	(C)	(C)	(C)	S	S	C
19	C	C	C	M	C	C	C	S	C	S	C	(C)
20	S	C	S	M	C	(C)	(C)	M	S	S	C	(C)
21	C	(C)	S	C	C	S	C	M	S	(C)	C	C
22	C	C	S	C	C	S	(C)	C	C	S	(C)	(C)
23	C	S	C	C	(C)	C	M	(C)	S	C	C	C
24	C	S	C	C	C	(C)	S	S	C	S	C	S
25	S	M	C	C	C	C	S	S	C	C	C	S
26	S	M	S	S	S	M	S	S	C	(C)	G	C
27	(C)	(C)	C	(C)	C	M	C	S	C	M	S	C
28	C	C	(C)	S	(C)	S	S	S	(C)	M	(C)	C
29	S	...	C	C	S	S	C	C	C	VG	C	M
30	(C)	...	C	C	C	C	C	C	M	M	C	S
31	C	...	C	...	C	...	C	C	...	S	...	C
C	21	20	21	22	21	19	21	18	17	13	16	19
S	6	4	10	6	7	8	9	10	9	11	13	10
M	3	4	...	2	3	3	1	3	4	5	...	2
G	1	...	...	...	...	...	...	...	...	1	1	...
VG	...	...	...	...	...	...	...	...	...	1	...	...

C=Calm. S=Slight. M=Moderate. G=Great. VG=Very Great. (C)=Selected quiet day.

CHAPTER III

TIDES

BY R.B. MATHUR, B.A.

1. Tidal observations. During the year under report, registration by the automatic tide-gauges was continued at the following seven stations:

Aden, Karāchi (Manora), Bombay (Apollo Bandar), Madras, Calcutta (Kidderpore), Rangoon and Basrah.

These observations were carried out under the supervision of the Survey of India, immediate control of each observatory being entrusted to the local port officials. Automatic registrations were also continued at Colombo and Trincomalee under the supervision of the Superintendent Trigonometrical Surveys, Ceylon, who supplied new values for mean sea-level at these places, showing no appreciable change.

In addition, the actual times and heights of high and low water were observed on tide-poles (during daylight only), under the supervision of the local port officials at Bhāvnagar, Chittagong, and Akyab.

A complete list of stations at which tidal registrations have been carried out, since the commencement of tidal operations in India in 1874, is given in Geodetic Report Vol. V, pp. 31–33.

2. Inspections. The tidal observatory at Kidderpore was inspected in August, that at Karāchi in December 1931, and that at Bombay in April 1932. The Kidderpore observatory was moved by the Port authorities from its previous site on the 1st March and reopened at Garden Reach, about a mile down stream, on the 17th March 1932.

All the inspections were carried out by the local port officials. No inspection reports have been received during the year from Aden, Madras and Rangoon.

Except at Basrah, the automatic gauges at all the ports have worked satisfactorily with few minor stoppages. The tide-gauge at Basrah, which is of a smaller type went out of order on several occasions between the date of its removal to Margil on the 27th April 1931 and the end of the year (see Table 6, page 33). It was dismantled for cleaning from the 1st January to the 1st February 1932, and was then found to work better.

3. Harmonic analysis. Computations are in progress for the determination of the necessary constants for the prediction of the tides at Chāndbāli and Shortt Island, Orissa Coast, and will be completed shortly. The predictions for these ports will be included for the first time in *Tide-tables of the Indian Ocean for the year 1934.*

The data for the analysis include hourly day and night readings, supplied by the Port Officer, Orissa ports, for the period 1st May 1931 to 4th May 1932.

4. Corrections to predictions. Empirical corrections have been applied to the predicted tides for 1933, in the case of Basrah, Kidderpore, Chittagong and Rangoon. The corrections for Chittagong and Rangoon are given in Tables 2 and 3, respectively; they differ very slightly from those for 1932, and are similarly derived. The corrections for Kidderpore are the same as those for 1932, given in the Geodetic Report Vol. VI, pp. 36–37.

5. Basrah predictions. These commenced with the predictions for 1917. From comparisons with the actual times and heights from year to year it has been obvious that the predictions are not quite satisfactory. The port is much affected by the peculiar behaviour of the floods of the Tigris and Euphrates, and is about 70 miles from the sea.

In order to improve them, an empirical correction of +44 minutes was applied to all predicted times of high and low water for 1927, and corrections varying from +10 to +63 minutes (Geodetic Report Vol. III, p. 61), were applied to the times of the 1928 predictions. Before the 1929 predictions were taken up, corrections were applied to the original charts supplied by the National Physical Laboratory, Teddington, and a new set of time and height charts was prepared. These corrections were derived from the differences of the predicted and actual values of times and heights for the period 1923–27 (Geodetic Report Vol. IV, pp. 34–35). The predictions from 1929 to 1932 were based on these new charts.

In March and April 1928, the Tidal Assistant inspected the observatory with a view to making the recording of actual values more reliable, and as a result an empirical table of corrections to times has been prepared (Table 1). But it has been found from a comparison of the actual tides of 1932, that there would be no improvement if these corrections were applied to the 1932 predictions. Consequently there is little prospect that the 1933 tide-tables, the predictions for which make use of these corrections, will prove accurate.

The method of prediction for riverain ports is based on the assumption that the diurnal inequality is small, but in the case of Basrah it is at times quite large. It seems likely that the method of predictions which has proved fairly satisfactory for Indian riverain ports, cannot be adapted to Basrah, and that good predictions will not be obtained without serious research, which the Survey of India is not at present in a position to undertake. The problem is one that could probably best be dealt with by the Liverpool Tidal Institute. For their immediate needs the port authorities have devised a system of empirical corrections to the Admiralty predictions for Shatt-al-Arab bar at the mouth of the river, which has been giving better results than the Survey of India predictions, and the latter will be discontinued from 1934.

6. Tide-tables. The Tide-tables for 1933, have been prepared and issued. They contain information similar to those for 1931 (Geodetic Report Vol. VI, p. 34) i.e. daily predictions for 68 standard ports, non-harmonic constants and tidal differences for about 470 ports and anchorages, in the Indian Ocean and the Far East, and harmonic constants for about 170 ports. Separate tide-tables in pamphlet form have also been published for Bombay, the Hooghly River and the Rangoon River. Advance predictions for 1933 for the following 14 ports were sent to the Hydrographer of the Navy in December 1931, in exchange for information received from him, for inclusion in the Admiralty Tide-tables: Suez, Aden, Bushire, Karāchi, Bhāvnagar, Bombay, Mormugao, Colombo, Trincomalee, Madras, Dublat (Hooghly River), Chittagong, Elephant Point (Rangoon River) and Mergui.

Similarly advance predictions for Karāchi, Bombay, Colombo, Madras and Dublat were also sent to the United States, and those for Bombay, Colombo and Dublat to the Japanese, Hydrographic departments. The amount realized from the sale of tide-tables during the year ending 30th September 1932 was Rs. 6,064/14/- exclusive of agents' commission.

7. Accuracy of predictions. Tables 5 to 17 have been prepared from comparisons made between the predicted and actual times and heights of high and low water for 1931, at the 12 stations mentioned in paragraph 1 and at Pilakāt or Deserters' Creek, Rangoon river. The 1931 predictions for the ports mentioned in these tables are practically of the same standard as those for the previous year except in the case of Bhāvnagar and Trincomalee, the former being slightly worse and the latter somewhat better, chiefly as regards the number of errors exceeding 30 minutes and 1 foot. The greatest differences between the predicted and actual heights of low water, as registered by the automatic tide-gauges, at the riverain ports are given in Table 4.

TABLE 1. *Time corrections applied to Basrah for 1933.*

Month	Tide	Dates					
		1st-5th	6th-10th	11th-15th	16th-20th	21st-25th	26th-31st
		minutes	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
January ...	High	0	− 3	− 6	− 8	+ 3	+ 14
	Low	+ 27	+ 23	+ 19	+ 15	+ 39	+ 63
February ...	High	+ 26	+ 17	+ 8	− 2	0	+ 2
	Low	+ 86	+ 61	+ 36	+ 12	+ 15	+ 18
March ...	High	+ 5	− 3	− 11	− 19	− 14	− 9
	Low	+ 22	+ 12	+ 2	− 8	− 1	+ 6
April ...	High	− 5	0	+ 5	+ 9	+ 15	+ 21
	Low	+ 12	+ 14	+ 16	+ 18	+ 27	+ 36
May ...	High	+ 28	+ 14	0	− 14	− 24	− 34
	Low	+ 44	+ 28	+ 12	− 4	− 10	− 16
June ...	High	− 43	− 41	− 39	− 36	− 25	− 14
	Low	− 22	− 23	− 24	− 24	− 9	+ 6
July ...	High	− 2	− 2	− 2	− 2	− 2	− 2
	Low	+ 21	+ 21	+ 21	+ 21	+ 15	+ 9
August ...	High	− 2	+ 4	+ 10	+ 15	+ 12	+ 9
	Low	+ 4	+ 11	+ 18	+ 25	+ 23	+ 21
September	High	+ 7	+ 5	+ 3	+ 2	+ 5	+ 8
	Low	+ 20	+ 21	+ 22	+ 22	+ 25	+ 28
October ...	High	+ 11	+ 7	+ 3	0	+ 2	+ 4
	Low	+ 32	+ 29	+ 26	+ 22	+ 25	+ 28
November	High	+ 7	+ 7	+ 7	+ 7	+ 1	− 5
	Low	+ 30	+ 31	+ 32	+ 33	+ 27	+ 21
December	High	− 10	− 16	− 20	− 26	− 17	− 8
	Low	+ 15	+ 13	+ 11	+ 8	+ 14	+ 20

The above corrections are based on the mean fortnightly results of the comparisons between the predicted and actual times from August 1929 to the middle of November 1931, computed for 5-day periods.

TABLE 2. *Corrections applied to Chittagong for 1933.*

Month	Tide	Dates			
		1st-15th		16th-31st	
		Time	Height	Time	Height
		minutes	*feet*	*minutes*	*feet*
January	High	+ 11	+0·3	+ 10	+0·2
	Low	+ 13	+0·7	+ 7	+0·7
February	High	+ 6	+0·3	+ 7	+0·2
	Low	+ 8	+0·8	+ 4	+0·7
March	High	+ 8	+0·1	+ 7	−0·1
	Low	+ 4	+0·6	+ 5	+0·5
April	High	+ 5	+0·1	+ 10	0·0
	Low	+ 6	+0·6	+ 11	+0·4
May	High	+ 13	−0·1	+ 11	−0·2
	Low	+ 12	+0·5	+ 11	+0·4
June	High	+ 10	+0·3	+ 8	+0·3
	Low	+ 13	+0·9	+ 11	+1·1
July	High	+ 9	0·0	+ 10	+0·1
	Low	+ 9	+0·5	+ 7	+0·7
August	High	+ 8	+0·2	+ 9	+0·3
	Low	+ 8	+0·7	+ 10	+0·9
September	High	+ 13	+0·1	+ 15	0·0
	Low	+ 14	+0·8	+ 17	+0·8
October	High	+ 20	+0·3	+ 21	+0·2
	Low	+ 21	+0·9	+ 20	+0·8
November	High	+ 22	−0·1	+ 19	+0·3
	Low	+ 23	+0·5	+ 21	+0·8
December	High	+ 18	+0·2	+ 12	+0·4
	Low	+ 16	+0·6	+ 12	+0·7

The above corrections are based on the mean fortnightly results of the comparisons between the predicted and actual times and heights from 1923 to 1930. (These corrections are slightly different from those for 1932 given in Geodetic Report Vol. VII, p. 34, the latter being based on similar data from 1923 to the first 8 months, and not the end, of 1930).

TABLE 3. *Time corrections applied to Rangoon for 1933.*

Month	Tide	Dates					
		1st-5th	6th-10th	11th-15th	16th-20th	21st-25th	26th-31st
		minutes	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
January ...	High	− 11	− 14	− 17	− 20	− 22	− 22
	Low	− 6	− 8	− 12	− 16	− 19	− 18
February ...	High	− 22	− 22	− 22	− 23	− 24	− 23
	Low	− 17	− 17	− 17	− 18	− 18	− 17
March ...	High	− 21	− 19	− 17	− 16	− 15	− 14
	Low	− 16	− 15	− 14	− 13	− 12	− 11
April ...	High	− 13	− 11	− 9	− 7	− 6	− 6
	Low	− 10	− 10	− 7	− 5	− 3	− 3
May ...	High	− 5	− 4	− 4	− 5	− 6	− 6
	Low	− 4	− 4	− 4	− 4	− 5	− 6
June ...	High	− 5	− 5	− 8	− 11	− 13	− 14
	Low	− 7	− 8	− 8	− 8	− 9	− 10
July ...	High	− 14	− 15	− 17	− 19	− 21	− 20
	Low	− 12	− 14	− 15	− 15	− 16	− 16
August ..	High	− 20	− 19	− 19	− 19	− 19	− 17
	Low	− 16	− 15	− 14	− 12	− 10	− 9
September	High	− 14	− 12	− 8	− 5	− 2	− 2
	Low	− 8	− 7	− 5	− 3	− 1	+ 1
October	High	− 2	− 2	− 1	+ 1	+ 2	+ 4
	Low	+ 2	+ 4	+ 6	+ 8	+ 9	+ 10
November	High	+ 5	+ 6	+ 6	+ 7	+ 7	+ 5
	Low	+ 11	+ 11	+ 11	+ 10	+ 9	+ 8
December	High	+ 4	+ 3	0	− 3	− 6	− 8
	Low	+ 7	+ 5	+ 3	0	− 3	− 4

The above corrections are based on the mean fortnightly results of the comparisons between the predicted and actual times from 1927 to 1931, computed for 5-day periods.

TABLE 4. *Greatest differences between predicted and actual heights of low water for 1931 at riverain ports with automatic tide-gauges.*

Serial number	Port	Predicted *minus* Actual	Date
		feet	
1	Basrah ...	+ 2·8	18th May—afternoon.
2	Kidderpore (Calcutta)...	− 1·7	14th and 27th October and 10th November—morning.
3	Rangoon ...	+ 2·2	29th and 30th October—morning.

TABLE 5. *Mean errors E_1* and E_2* for 1931.*

ADEN

PERIOD 1931	MEAN ERRORS (Predicted – actual)											
	E_1*								E_2*			
	H. W.				L. W.				H. W.		L. W.	
	Time		Height		Time		Height		Time	Ht.	Time	Ht.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*
	+	–	+	–	+	–	+	–				
Jan. 1-15		7·6	0·2			0·7	0·2		18·5	0·2	9·5	0·2
16-31	1·6		0·1		2·6		0·1		10·9	0·2	11·0	0·2
Feb. 1-15		9·3		0·0	4·2			0·0	15·1	0·2	13·1	0·1
16-28	3·3		0·0		8·5			0·0	7·8	0·2	11·5	0·1
† Mar. 1-15	2·7			0·1	2·2		0·0		13·3	0·1	10·5	0·2
16-31	7·5		0·0		1·4			0·0	8·4	0·1	11·1	0·1
† April 1-15	3·4			0·0		1·5	0·1		7·7	0·1	9·4	0·2
16-30	8·5			0·0	7·5			0·0	11·2	0·1	12·5	0·1
† May 1-15	6·2			0·1	1·3			0·1	10·8	0·1	18·2	0·3
16-31	4·3			0·1	0·2			0·2	5·8	0·1	6·5	0·2
June 1-15		1·7		0·1	0·5			0·2	9·0	0·2	18·6	0·2
16-30	2·6			0·4	0·7			0·3	5·3	0·4	3·8	0·3
July 1-15		16·2		0·2	5·3			0·3	22·2	0·2	9·7	0·3
16-31		6·5		0·1		1·2		0·1	9·6	0·2	6·7	0·2
Aug. 1-15		5·8	0·1		2·2		0·0		9·8	0·2	7·7	0·2
16-31		17·7	0·1			7·0	0·1		17·9	0·2	9·4	0·2
Sept. 1-15		9·6		0·3	0·5			0·4	10·5	0·3	6·0	0·4
16-30		11·7	0·1			15·7		0·1	14·9	0·1	17·0	0·1
Oct. 1-15		3·7	0·1			6·2		0·1	7·0	0·1	6·9	0·2
16-31		5·2	0·3			7·5	0·2		10·2	0·3	10·0	0·2
Nov. 1-15		5·6	0·3			5·9	0·1		8·7	0·3	6·8	0·2
16-30		1·9	0·1			8·7		0·0	9·1	0·2	11·9	0·1
Dec. 1-15		3·7	0·0			6·7		0·1	6·2	0·1	8·8	0·2
16-31		1·6	0·2			3·0	0·1		8·4	0·2	5·4	0·2

TABLE 6. *Mean errors E_1* and E_2* for 1931.*

BASRAH

PERIOD 1931	MEAN ERRORS (Predicted – actual)												Number of errors exceeding			
	E_1*								E_2*				30 *minutes* of time		0·5 *foot* of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	−	+	−	+	−	+	−								
Jan. 1-15	2·0			0·3	22·7		0·0		36·0	0·3	62·6	0·5	14	24	4	16
16-19		24·9		0·7		7·8		0·1	53·1	0·7	64·2	0·4	4	6	3	0
Feb. 1-15	The tide-gauge was out of working order from 19th January to 27th April.															
16-28																
Mar. 1-15																
16-31																
April 1-15																
27-30	21·5		0·2		20·6		1·0		48·5	0·2	39·4	1·0	5	2	0	6
May 1-15	5·3		0·7		33 0		1·5		60·8	0·8	61·9	1·5	22	17	17	26
16-31		2·9	0·8			13·2	1·4		9·0	0·8	46·7	1·4	15	25	25	27
June 1-15	Registrations not available from 1st to 16th June; clock stopped.															
16-28		35·7	0·4			23·5	0·8		46·5	0·4	55·5	0·8	13	16	7	13
July 6-15	16·6		0·1		41·9		0·6		38·5	0·4	68·3	0·7	12	15	3	13
16-31		4·5		0·3	11·6		0·1		32·8	0·4	59·6	0·4	14	24	11	9
Aug. 1-3 10-15	17·9			0·3	15·8			0·2	51·1	0·4	67·5	0·4	9	14	6	3
16, 17 & 31	1·8			0·2	10·5			0·3	20·8	0·4	37·0	0·3	1	2	1	1
Sept. 1-15	8·5			0·4	30·0			0·4	31·5	0·5	45·5	0·4	11	12	12	7
16-21 28-30		17·1		0·1	10·3		0·2		31·6	0·7	40·8	0·8	5	11	11	7
Oct. 1-15		5·8	0·2		28·9		0·5		40·6	0·5	53·3	0·8	17	19	10	20
16-31		48·3		0·2		16·2	0 2		62·9	0·5	63·4	0·5	26	20	11	9
Nov. 1-16		0·7		0·2	12·1		0·1		41·8	0·3	41·9	0·5	15	8	8	3
16-30	The tide-gauge was out of working order from 16th November 1931 to 31st January 1932.															
Dec. 1-15																
16-31																
TOTALS...	73·6	139·9	2·4	2·7	237·4	60·7	6·4	1·0	605·5	7·3	807·6	10·4	183	215	129	160
MEANS...	− 4·4		− 0·0		+ 11·8		+ 0·4		40·4	0·5	53·8	0·7				

*E_1 is with regard to sign: E_2 is without regard to sign.

TABLE 7. *Mean errors E_1* and E_2* for 1931.*

KARĀCHI

PERIOD 1931	MEAN ERRORS (Predicted − actual)												Number of errors exceeding			
	E_1*								E_2*				30 minutes of time		0·9 foot of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	−	+	−	+	−	+	−								
Jan. 1-15	3·6			0·3	3·1			0·2	9·9	0·3	9·8	0·2	0	0	0	0
16-31		2·5		0·3		2·7		0·1	13·3	0·4	17·3	0·2	2	7	0	0
Feb. 1-15		2·3		0·1	0·6		0·2		10·5	0·2	11·1	0·3	1	2	0	0
16-28		0·1		0·3	3·0			0·1	9·9	0·3	18·8	0·2	1	7	0	0
Mar. 1-15	0·2			0·2	9·2			0·0	7·5	0·2	13·1	0·2	0	1	0	0
16-31		1·8		0·3		2·9		0·2	8·5	0·3	12·2	0·2	1	3	0	0
April 1-15	4·7			0·2	0·2			0·0	8·5	0·2	9·5	0·1	2	1	0	0
16-30		2·2		0·2	0·7			0·0	7·0	0·3	9·1	0·2	0	0	0	0
May 1-15		2·3		0·3		4·0		0·1	6·1	0·3	8·7	0·1	0	1	0	0
16-31		2·2		0·0	2·7		0·3		6·9	0·2	15·7	0·3	0	2	0	0
June 1-15		1·4		0·5		2·5		0·4	11·7	0·5	15·3	0·5	2	1	5	[illegible]
16-30	3·4			0·3	0·1			0·0	6·7	0·4	12·3	0·2	0	1	0	0
July 1-15		0·9		0·4		4·1		0·2	15·6	0·4	14·4	0·3	3	3	2	0
16-31	2·3			0·2		0·5	0·1		7·4	0·2	8·5	0·2	0	0	0	0
Aug. 1-15		8·0		0·5	2·0			0·3	12·6	0·5	10·8	0·4	2	1	1	0
16-31		0·9		0·3		0·2	0·0		7·2	0·3	11·2	0·2	1	1	0	0
Sep. 1-15	4·6			0·1	9·3		0·1		10·2	0·2	13·3	0·2	2	4	0	0
16-30		3·2		0·0		0·9	0·1		8·2	0·1	7·5	0·2	1	0	0	0
Oct. 1-15	3·0		0·0		11·0		0·2		5·8	0·2	15·9	0·3	0	5	0	0
16-31	0·2			0·0		2·8	0·2		8·5	0·2	9·7	0·2	2	0	0	0
Nov. 1-15	0·1			0·2	5·8		0·0		6·6	0·2	13·1	0·3	0	3	0	1
16-30		0·9		0·3		2·7		0·1	5·8	0·3	11·3	0·2	0	1	0	0
Dec. 1-15		1·7		0·5	7·4			0·4	6·8	0·5	15·9	0·4	0	3	2	1
16-31	8·4			0·3	7·1			0·1	13·5	0·4	13·4	0·2	1	4	0	0
TOTALS ...	30·5	30·4	0·0	5·8	62·2	23·3	1·2	2·2	214·7	7·1	297·9	5·8	21	51	10	7
MEANS ...	+ 0·0		− 0·2		+ 1·6		− 0·0		8·9	0·3	12·4	0·2				

* E_1 is with regard to sign: E_2 is without regard to sign.

TABLE 8. *Mean errors E_1* and E_2* for 1931.*

BHĀVNAGAR

PERIOD 1931	MEAN ERRORS (Predicted – actual†)												Number of errors exceeding			
	E₁*								E₂*				30 minutes of time		1·0 foot of height	
	H. W.				L. W				H. W.		L. W.					
	Time		Height		Time		Height		Time	Ht.	Time	Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		feet		minutes		feet		minutes	feet	minutes	feet				
	+	–	+	–	+	–	+	–								
Jan. 1-15	11·7			0·2		5·9		0·9	22·7	0·6	14·8	1·0	6	0	2	6
16-31	19·9			0·5	0·8		0·0		19·9	0·7	11·5	0·8	2	0	5	4
Feb. 1-15	15·7		0·1			15·4		1·2	16·4	0·8	21·1	1·7	2	4	6	7
16-28	18·7			0·1		4·3	0·0		18·7	0·4	18·5	0·7	2	2	1	2
Mar. 1-15	11·1		0·0			12·1		1·6	13·9	0·7	17·1	1·9	0	2	3	7
16-31	16·1			0·2		7·4		0·0	16·3	0·4	17·8	0·4	1	1	1	0
April 1-15	10·3			0·2		11·0		1·7	11·5	0·7	14·1	1·7	1	0	4	7
16-30	11·7			0·3		7·7		0·2	13·1	0·5	13·0	0·4	0	0	2	1
May 1-15		1·9		0·4		16·7		1·1	8·7	0·9	16·7	1·4	0	2	5	5
16-31	11·8		0·1			13·2		0·1	14·2	0·6	14·6	0·8	1	0	0	3
June 1-15	4·2			0·6		3·2		0·2	8·1	0·8	11·5	0·8	0	0	5	3
16-30	11·1			0·1		11·8	0·0		13·5	0·5	12·2	0·3	0	0	1	1
July 1-15	12·3			0·5		5·3	0·0		12·3	0·6	8·3	0·6	0	0	4	1
16-31	2·6			0·5		32·9		0·2	8·1	0·8	32·9	0·8	0	8	4	5
Aug. 1-15	4·2			0·6		14·3		0·0	15·1	0·6	21·1	0·7	1	4	1	4
16-31	9·8			1·1		36·5	0·5		10·4	1·1	36·5	1·2	0	10	9	9
Sep. 1-15	5·8			0·3		27·4	0·0		12·6	0·6	34·1	1·4	0	6	0	10
16-30	5·2			0·3		17·3	0·7		9·7	0·5	18·0	1·0	0	1	2	5
Oct. 1-15	3·9			0·6		19·6		0·4	11·7	0·8	27·9	2·2	0	6	6	12
16-31	8·3			0·3		25·1	0·4		11·5	0·4	25·1	0·7	0	4	0	3
Nov. 1-15	7·2			0·3		29·1		0·8	23·2	0·8	32·1	1·6	5	7	3	8
16-30	6·7			0·4		13·2	0·2		13·6	0·4	13·3	0·4	0	0	1	0
Dec. 1-15	11·3			0·8		23·0		1·2	21·3	0·9	23·1	1·3	3	5	5	8
16-31	15·9		0·0			5·1		0·1	17·6	0·7	10·6	0·8	0	2	2	3
Totals...	235·5	1·9	0·2	8·3	0·8	357·5	1·8	9·7	344·1	15·8	465·9	24·6	24	64	72	11
Means ...	+ 9·7		– 0·3		– 14·9		– 0·3		14·3	0·7	19·4	1·0				

* E_1 is with regard to sign: E_2 is without regard to sign.
† Actual values are tide-pole readings during daylight only.

TABLE 9. *Mean errors E_1* and E_2* for 1931.*

BOMBAY (APOLLO BANDAR)

PERIOD 1931	MEAN ERRORS (Predicted – actual)												Number of errors exceeding			
	E_1*								E_2*				30 minutes of time		1·0 foot of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		feet		minutes		feet		minutes	feet	minutes	feet				
	+	–	+	–	+	–	+	–								
Jan. 1-15		9·0		0·2		10·3		0·4	11·1	0·3	11·9	0·4	1	0	0	0
16-31		11·2		0·1		12·1		0·1	13·7	0·3	12·9	0·2	4	3	0	0
Feb. 1-15		4·9	0·1			6·3	0·0		8·0	0·3	8·7	0·2	0	0	0	0
16-28		7·6		0·1		8·9		0·2	9·6	0·2	12·0	0·3	0	1	0	0
Mar. 1-15		6·3		0·2		14·6		0·2	12·4	0·3	15·3	0·3	1	1	0	0
16-31		5·5		0·4		3·9		0 2	10·4	0·4	9·9	0·3	0	0	2	0
April 1-15		2·0		0·2		10·3		0·1	12·6	0·4	13·0	0·3	1	1	0	0
16-30		6·7		0·4		10·6		0·3	12·7	0·5	13·0	0·3	0	1	0	0
May 1-15		13·9		0·2		23·3		0·1	16·6	0·4	23·3	0·2	3	8	1	0
16-31		8·9		0·0		14·2	0·2		11·0	0·3	14·5	0·3	0	0	0	0
June 1-15		3·3		0·3		10·4		0·2	6·8	0·3	12·9	0·4	1	1	0	0
16-30		7·0		0·1		10·8		0·0	8·3	0·2	11·4	0·3	0	1	0	0
July 7-15		9·7		0·4		6·8		0·5	14·8	0·5	16·3	0·5	1	1	2	0
16-31		1·9		0·2		1·2		0·4	9·3	0·4	6·7	0·5	1	0	0	3
Aug. 1-15		8·4		0·5		1·8		0·6	13·8	0·5	8·7	0·6	1	1	1	4
16-31		4·9		0·1	3·2			0·4	9·3	0·3	11·7	0·4	0	3	0	2
Sept. 1-15	1·1		0·1		3·2			0·0	13·9	0·3	14·3	0·2	4	3	0	0
16-30		2·1	0·3		2·8			0·1	7·6	0·3	8·2	0·3	0	2	0	1
Oct. 1-15		2·2		0·1	1·9			0·1	6·5	0·2	10·5	0·3	0	2	0	0
16-31	2·4		0·1			2·4		0·0	6·1	0·2	6·2	0·3	0	1	0	0
Nov. 1-15	1·7		0·0			1·0		0·1	5·6	0·3	7·3	0·3	0	0	0	0
16-30	2·4		0·0			3·7		0·1	7·2	0·3	11·0	0·3	0	3	0	0
Dec. 1-15		4·8		0·3		6·6		0·3	9·3	0·4	8·1	0·4	1	0	0	1
16-31		8·5		0·0		5·0		0·2	11·5	0·2	9·1	0·2	2	1	0	0
TOTALS ...	7·6	128·8	0·6	3·8	11·1	164·2	0·2	4·6	248·1	7·8	276·9	7·8	21	34	6	11
MEANS ...	– 5·1		– 0·1		– 6·4		– 0·2		10·3	0·3	11·5	0·3				

* E_1 is with regard to sign : E_2 is without regard to sign.

TABLE 10. *Mean errors E_1* and E_2* for 1931.*

COLOMBO

PERIOD 1931	MEAN ERRORS (Predicted—actual)													Number of errors exceeding			
	E₁*								E₂*				30 *minutes* of time		0·3 *foot* of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	−	+	−	+	−	+	−								
Jan. 1-15	6·0			0·2	12·4			0·2	9·4	0·2	21·0	0·2	0	6	5	4
16-31	12·2		0·0		8·8		0·1		16·6	0·1	11·5	0·1	5	3	0	1
Feb. 1-15	2·8			0·0	13·4			0·0	19·0	0·1	27·6	0·1	4	6	0	0
16-28	8·1			0·3	12·3			0·2	9·6	0·3	12·7	0·2	1	2	5	1
Mar. 1-15	7·3			0·3	1·9			0·2	18·4	0·3	17·6	0·2	4	4	8	6
16-31	9·9			0·1	8·8			0·0	11·6	0·2	12·1	0·1	2	2	0	0
April 1-15	4·6		0·1		14·3		0·1		15·3	0·1	17·2	0·1	1	4	1	1
16-30	17·0			0·1	12·0		0·0		18·0	0·1	24·1	0·1	5	5	1	0
May 1-15	7·8			0·0	6·3		0·2		14·4	0·1	25·4	0·3	3	8	2	8
16-31	9·8			0·1	12·1		0·1		19·8	0·2	18·6	0·1	5	5	1	4
June 1-15	17·1			0·2	18·0			0·1	19·1	0·2	19·8	0·1	4	5	4	1
16-30	5·9			0·2	13·8			0·1	19·4	0·2	20·6	0·1	5	6	3	2
July 1-15	19·8			0·1	5·1		0·0		20·7	0·1	16·7	0·1	6	4	1	0
16-31	2·1			0·2	0·5			0·2	12·8	0·2	15·0	0·3	3	5	6	7
Aug. 1-15	9·6			0·2	7·3			0·3	21·4	0·2	15·4	0·3	3	2	6	10
16-31	16·4			0·1	12·1			0·1	17·6	0·1	19·4	0·2	4	3	0	10
Sept. 1-15	20·5			0·2	16·7			0·0	25·0	0·2	20·9	0·2	7	5	5	4
16-30	4·5			0·0	12·0		0·2		27·6	0·1	26·3	0·2	5	2	0	3
Oct. 1-15	19·6		0·1		15·7		0·3		20·0	0·2	16·3	0·3	5	1	3	8
16-31	11·1		0·2		10·6		0·3		12·5	0·2	11·3	0·3	1	0	5	12
Nov. 1-15	13·0			0·0	4·8		0·2		14·0	0·2	15·3	0·3	4	3	5	10
16-30	11·9			0·2	11·4			0·1	14·7	0·2	14·1	0·2	1	2	4	3
Dec. 1-15	2·4			0·4	2·4			0·3	11·6	0·4	14·9	0·4	1	2	20	15
16-31	8·3			0·1	7·5			0·0	14·1	0·2	11·1	0·1	2	1	4	1
TOTALS	247·7		0·4	3·0	240·2		1·5	1·8	402·6	4·4	424·9	4·6	81	86	89	111
MEANS ...	+10·3		−0·1		+10·0		−0·0		16·8	0·2	17·7	0·2				

* E_1 is with regard to sign: E_2 is without regard to sign.

TABLE 11. *Mean errors E_1* and E_2* for 1931.*

TRINCOMALEE

PERIOD 1931	MEAN ERRORS (Predicted – actual)												Number of errors exceeding			
	E_1*								E_2*				30 minutes of time		0·2 foot of height	
	H. W.				L. W.				H. W.		L. W.					
	Time		Height		Time		Height		Time	Ht	Time	Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	–	+	–	+	–	+	–								
Jan. 1-15	26·8			0·4	19·3			0·1	30·6	0·4	22·7	0·1	11	8	23	3
16-31	38·3			0·3	38·4			0·1	40·0	0·3	40·7	0·2	12	15	23	9
Feb. 1-15	3·9			0·4	7·9			0·3	17·1	0·4	17·1	0·3	5	5	24	14
16-28	7·6			0·3		12·9		0·3	22·1	0·3	29·7	0·	5	11	18	19
Mar. 1-15	16·4			0·4	15·1			0·5	30·1	0·4	36·1	0·5	9	14	24	18
16-31		3·4		0·4	4·5			0·3	26·1	0·4	28·6	0·3	7	13	28	19
April 1-15	14·3			0·4	15·2			0·4	20·6	0·4	40·2	0·4	6	14	24	18
16-30	28·2			0·4	20·0			0·4	28·6	0·4	21·8	0·4	14	7	28	21
May 1-15	58·2			0·3	66·7			0·3	58·2	0·3	66·7	0·3	19	25	20	14
16-31	15·7			0·7	23·0			0·4	26·2	0·7	27·0	0·4	10	11	31	25
June 1-15		4·7		0·5		14·8		0·2	29·8	0·5	30·2	0·2	11	12	29	12
16-30	17·8			0·6	29·6			0·2	22·5	0·6	32·4	0·2	5	13	28	9
July 1-15		22·6		0·1		17·2		0·1	46·9	0·2	47·9	0·2	16	14	11	9
16-31		42·9		0·3		39·3		0·2	49·5	0·3	43·3	0·3	21	16	16	14
Aug. 1-15	35·4			0·0	22·0			0·5	47·1	0·1	36·5	0·5	12	7	0	16
16-31	62·4			0·1	36·1			0·4	62·4	0·1	38·3	0·5	15	10	3	7
Sept. 1-15	61·7			0·2	46·6			0·2	65·9	0·3	54·9	0·4	16	15	11	14
16-30	36·4			0·1	36·6			0·2	45·4	0·1	45·8	0·2	17	21	1	7
Oct. 1-15	11·5		0·0			2·8		0·1	37·0	0·1	35·4	0·2	12	13	3	11
16-31		6·9		0·5		26·6		0·1	32·6	0·5	37·8	0·3	11	11	24	16
Nov. 1-15	38·0			0·3	24·1			0·2	38·8	0·4	43·3	0·3	10	16	14	15
16-30		21·4		0·3		35·3		0·2	39·9	0·3	49·8	0·3	11	8	11	10
Dec. 1-15	0·2			0·8	2·9			0·4	28·0	0·8	32·7	0·4	11	7	28	22
16-31	7·0			0·5		19·7		0·4	23·5	0·5	39·6	0·4	7	10	25	25
TOTALS ...	479·8	101·9	0·0	8·3	408·0	168·6		6·5	868·9	8·8	898·5	7·6	273	296	447	350
MEANS ...	+ 15·7		– 0·3		+ 10·0		– 0·3		36·2	0·4	37·4	0·3				

* E_1 is with regard to sign: E_2 is without regard to sign.

TABLE 12. *Mean errors E_1* and E_2* for 1931.*

MADRAS

PERIOD 1931	MEAN ERRORS (Predicted—actual)												Number of errors exceeding			
	E_1*								E_2*				30 minutes of time		0·4 foot of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		feet		minutes		feet		minutes	feet	minutes	feet				
	+	−	+	−	+	−	+	−								
Jan. 1-15		14·8		0·2		16·1		0·3	15·0	0·2	17·0	0·3	1	2	0	3
16-31		5·0		0·0		7·3		0·0	5·5	0·1	7·8	0·1	0	0	0	0
Feb. 1-07		7·5		0·1		6·9		0·2	7·8	0·1	7·6	0·3	0	0	0	1
16-28	Readings faulty.															
Mar. 4-15	6·3			0·1	6·9			0·1	13·0	0·1	11·6	0·1	0	0	0	0
16-31	7·7			0·1	6·4			0·0	8·8	0·1	7·3	0·1	0	0	0	0
April 1-15	9·7			0·1	12·6		0·0		11·0	0·1	13·6	0·2	0	1	0	1
16-30	10·5		0·1		14·7		0·1		10·5	0·2	15·1	0·2	0	2	0	0
May 1-15	6·2		0·1		4·0		0·2		7·9	0·3	8·4	0·3	0	0	1	0
16-31	9·4			0·5	8·1			0·3	9·7	0·5	9·1	0·3	0	0	15	9
June 1-15	5·4			0·3	7·4			0·2	6·7	0·3	8·3	0·2	0	0	7	3
16-30	1·5			0·3		1·1		0·2	3·8	0·3	4·0	0·2	0	0	12	3
July 1-15	5·9			0·1	6·3			0·1	7·9	0·2	8·0	0·1	0	0	1	0
16-31	3·0			0·1	4·0			0·0	4·5	0·1	5·6	0·2	0	0	0	0
Aug. 1-15	4·6		0·2		5·7		0·2		5·9	0·2	6·2	0·2	0	0	0	4
16-31		3·2	0·2			2·9	0·3		7·6	0·2	9·9	0·3	0	0	1	6
Sept. 1-15	8·3			0·1	4·5			0·0	8·6	0·1	7·1	0·1	0	0	0	0
16-30	3·7			0·3	4·5			0·2	6·1	0·3	6·7	0·2	0	0	0	0
Oct. 1-15	3·7			0·2	3·6			0·1	6·6	0·2	7·5	0·2	0	0	2	2
16-31	1·1			0·5	2·3			0·3	5·9	0·5	5·1	0·4	1	0	18	15
Nov. 1-15	5·5			0·2	4·4			0·1	8·1	0·2	7·2	0·2	0	0	7	3
16-30	3·1			0·5	2·8			0·4	6·1	0·5	4·7	0·4	0	0	22	18
Dec. 1-15	4·5			0·6	0·1			0·5	6·0	0·6	6·0	0·5	0	0	22	16
16-31	9·4			0·5	9·0			0·3	10·3	0·5	9·8	0·3	0	0	16	3
TOTALS ...	109·5	30·5	0·6	4·8	107·3	34·3	0·8	3·3	183·3	5·9	193·6	5·4	2	5	124	87
MEANS ...	+ 3·4		− 0·2		+ 3·2		− 0·1		8·0	0·3	8·4	0·2				

* E_1 is with regard to sign: E_2 is without regard to sign.

TABLE 13. *Mean errors E_1* and E_2* for 1931.*

KIDDERPORE (CALCUTTA)

PERIOD 1931	MEAN ERRORS (Predicted − actual)												Number of errors exceedin			
	E_1*								E_2*				*30 minutes* of time		*1·0 foot* of height	
	H. W.				L. W.				H. W.		L. W.		H. W.	L. W.	H. W.	W.
	Time		Height		Time		Height		Time	Ht.	Time	Ht.				
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	−	+	−	+	−	+	−								
Jan. 1-15	2·2		0·0			7·8	0·3		9·0	0·2	9·4	0·4	0	2	0	2
16-31	0·3			0·2	0·8		0·3		12·6	0·2	6·5	0·5	0	0	0	4
Feb. 1-15	2·8			0·1		7·4	0·5		10·0	0·4	13·9	0·7	0	3	0	9
16-28	1·3			0·2	6·6		0·2		8·3	0·4	9·2	0·4	0	2	0	0
Mar. 1-15	1·8			0·5		5·5	0·6		10·0	0·5	13·0	0·6	0	1	0	3
16-31		1·0	0·0		0·1		0·5		9·5	0·5	7·1	0·6	0	1	1	2
April 1-15		3·6		0·2		5·7	0·5		12·1	0·4	14·6	0·6	0	4	1	2
16-30	5·4			0·4		1·3	0·0		10·1	0·4	10·2	0·3	0	0	1	1
May 1-15	6·6			0·9	3·5			0·2	12·4	0·9	13·1	0·4	4	3	8	2
16-31	5·8			0·6		8·0	0·1		10·8	0·8	16·4	0·3	0	4	8	0
June 1-15	0·1			0·1	9·0		0·0		9·2	0·4	15·6	0·4	0	4	1	0
16-30	1·6			0·2		11·1	0·2		10·3	0·2	13·1	0·4	0	3	0	3
July 1-15	1·8			0·1	2·5		0·1		9·8	0·2	8·7	0·4	0	0	0	0
16-31		4·6	0·2			12·0	0·4		10·1	0·6	14·2	0·6	1	5	5	3
Aug. 1-15	1·4			0·3	2·2		0·1		8·0	0·4	13·6	0·3	0	2	0	0
16-31	0·8			0·5		1·9	0·1		7·5	0·7	10·7	0·4	1	2	9	1
Sept. 1-15	1·3			0·4		0·9	0·1		8·4	0·4	20·1	0·3	1	6	0	0
16-30	6·9			1·1	4·5			0·5	9·1	1·1	12·3	0·5	0	1	16	4
Oct. 1-15	7·8			1·3	5·3			0·9	11·0	1·3	9·2	0·9	0	1	23	12
16-31	3·8			1·3	7·2			1·1	9·9	1·3	8·4	1·1	1	1	21	18
Nov. 1-15	5·3			1·3		7·6		1·2	9·0	1·3	18·0	1·2	0	5	21	19
16-30	3·7			1·0	7·4			0·8	6·4	1·0	8·9	0·8	0	2	10	6
Dec. 1-15	0·3			0·4		8·9		0·2	7·4	0·4	10·8	0·4	0	3	0	0
16-31	2·9			0·4	5·7			0·2	8·4	0·4	9·3	0·4	0	0	0	0
TOTALS	63·9	9·2	0·2	11·5	54·8	78·1	4·0	5·1	229·3	14·4	286·3	12·9	8	55	125	91
MEANS ..	+ 2·3		− 0·5		− 1·0		− 0·0		9·6	0·6	11·9	0·5				

* E_1 is with regard to sign: E_2 is without regard to sign.

TABLE 14. *Mean errors E_1* and E_2* for 1931.*

CHITTAGONG

PERIOD 1931	MEAN ERRORS (Predicted − actual†)												Number of errors exceeding			
	E_1*								E_2*				30 minutes of time		1·0 foot of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	−	+	−	+	−	+	−								
Jan. 1-15	5·6		0·1		2·9			0·1	6·8	0·1	4·3	0·3	0	0	0	0
16-31	2·6			0·2	0·6		0·1		4·4	0·3	3·8	0·2	0	0	1	1
Feb. 1-15	0·9			0·0		0·7		0·3	4·8	0·6	3·4	0·3	0	0	1	1
16-28		0·8	0·1			1·8	0·1		4·9	0·3	4·8	0·2	0	0	0	0
Mar. 1-15	1·5		0·2		3·5		0·1		6·1	0·2	4·3	0·6	0	0	0	1
16-31		0·9	0·5		0·0		0·4		8·3	0·5	7·8	0·5	0	0	0	0
April 1-15	5·7		0·1		5·9		0·2		8·0	0·7	6·4	0·4	0	0	4	1
16-30	0·1			0·1	5·5		0·3		9·8	0·3	9·3	0·4	0	0	0	0
May 1-15	6·1		0·2		3·5			0·1	9·1	0·7	6·6	0·5	0	0	1	0
16-31	3·4		0·3		6·9		0·3		5·8	0·5	7·2	0·4	0	0	3	0
June 1-15	3·1		0·4		9·2		0·6		4·7	0·5	9·2	0·7	0	0	3	5
16-30	2·5		0·2		10·8		0·3		5·1	0·3	12·1	0·3	0	0	0	0
July 1-15	3·6			0·4	9·4		0·1		5·2	0·5	9·9	0·5	0	0	2	0
16-31	3·8		0·2		8·8		0·3		6·1	0·4	8·8	0·6	0	0	1	1
Aug. 1-15	6·9		0·0		14·1		0·5		7·2	0·5	14·1	0·5	0	0	0	0
16-31		2·8		0·1	9·5		0·4		6·4	0·3	10·4	0·7	0	0	0	3
Sept. 1-15	0·1		0·1		1·0			0·3	5·1	0·7	9·1	0·4	0	0	3	0
16-30		12·1		0·1		2·2		0·0	12·1	0·4	5·1	0·4	0	0	1	1
Oct. 1-15		6·4		0·5		6·1		0·4	7·6	0·5	7·2	0·5	0	0	1	3
16-31		0·8		1·0	0·5			0·4	5·8	1·0	6·3	0·5	0	0	8	0
Nov. 1-15	5·1			0·7	3·5			0·5	5·1	0·7	4·9	0·7	0	0	4	5
16-30	3·7			0·4	3·7		0·1		5·1	0·4	5·7	0·2	0	0	1	0
Dec. 1-15	5·1			0·6	3·2			0·1	6·3	0·6	5·1	0·3	0	0	5	1
16-31	4·9			0·7	3·1		0·0		6·6	0·7	4·7	0·1	0	0	5	0
TOTALS...	64·7	23·8	2·4	4·8	105·6	10·8	3·8	2·2	156·4	11·7	170·5	10·2	0	0	44	23
MEANS ...	+ 1·7		− 0·1		+ 4·0		+0·1		6·5	0·6	7·1	0·4				

* E_1 is with regard to sign : E_2 is without regard to sign.
† Actual values are tide-pole readings during daylight only.

TABLE 15. *Mean errors E_1* and E_2* for 1931.*

AKYAB

PERIOD 1931	MEAN ERRORS (Predicted – actual†)												Number of errors exceeding			
	E_1*								E_2*				30 *minutes* of time		0·8 *foot* of height	
	H. W.				L. W.				H. W.		L. W.					
	Time		Height		Time		Height		Time	Ht.	Time	Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	–	+	–	+	–	+	–								
Jan. 1-15	5·3		0·1		5·5		0·1		5·3	0·2	5·5	0·3	0	0	0	0
16-31	6·6			0·1	6·1		0·4		6·6	0·1	6·1	0·4	0	0	0	1
Feb. 1-15	5·6		0·0		5·6			0·0	5·6	0·3	5·6	0·2	0	0	0	0
16-28	5·1			0·1	5·3			0·3	5·1	0·1	5·3	0·3	0	0	0	1
Mar. 1-15	5·4		0·2		4·2			0·2	5·4	0·2	6·2	0·5	0	0	0	1
16-31	6·3		0·1		5·6		0·1		6·3	0·2	5·6	0·2	0	0	0	0
April 1-15	6·4			0·0	6·5		0·1		6·4	0·2	6·5	0·2	0	0	0	0
16-30	5·3			0·1	4·7		0·3		5·3	0·3	4·7	0·3	0	0	0	2
May 1-15	5·7			0·2	5·7		0·1		5·7	0·3	5·7	0·2	0	0	0	0
16-31	6·4			0·1	6·5		0·1		6·4	0·2	6·5	0·3	0	0	0	0
June 1-15	6·4			0·1	6·0		0·2		6·4	0·1	6·0	0·2	0	0	0	0
16-30	5·6		0·0		5·3		0·0		5·6	0·2	5·3	0·1	0	0	0	0
July 1-15	6·1		0·1		5·5		0·1		6·1	0·2	5·5	0·1	0	0	1	0
16-31	5·5		0·2		4·8		0·1		6·0	0·2	4·8	0·2	0	0	0	0
Aug. 1-15	4·2		0·0		4·1		0·0		4·2	0·1	4·1	0·3	0	0	0	1
16-31	4·9		0·1		4·5		0·0		4·9	0·2	4·5	0·3	0	0	0	0
Sept. 1-15	4·6		0·2		4·9		0·2		4·6	0·3	4·9	0·2	0	0	0	0
16-30	5·5			0·1	5·7		0·2		5·5	0·2	5·7	0·3	0	0	0	0
Oct. 1-15	5·3		0·0		4·5		0·0		5·3	0·3	4·5	0·2	0	0	0	0
16-31	5·3			0·1	4·1		0·0		5·3	0·1	4·1	0·2	0	0	0	0
Nov. 1-15	4·5			0·0	4·7		0·1		4·5	0·2	4·7	0·2	0	0	0	0
16-30	4·7			0·2	4·7			0·1	4·7	0·3	4·7	0·2	0	0	0	0
Dec. 1-15	5·0		0·0		5·0		0·1		5·0	0·1	5·0	0·2	0	0	0	0
16-31	4·9			0·3	4·9		0·0		4·9	0·3	4·9	0·3	0	0	0	0
TOTALS ...	130·6		1·0	1·4	124·4		2·2	0·6	131·1	4·9	126·4	5·9	0	0	1	6
MEANS ...	+ 5·4		– 0·0		+ 5·2		+ 0·1		5·5	0·2	5·3	0·2				

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* E_1 is with regard to sign : E_2 is without regard to sign.

† Actual values are tide-pole readings during daylight only.

TABLE 16. *Mean errors E_1* and E_2* for 1931.*

ELEPHANT POINT (PILAKĀT CREEK)

PERIOD 1931	MEAN ERRORS (Predicted − actual†)												Number of errors exceeding			
	E1*								E2*				30 minutes of time		1·0 foot of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		feet		minutes		feet		minutes	feet	minutes	feet				
	+	−	+	−	+	−	+	−								
Jan. 1-15	29·3			0·2	11·0		0·1		29·3	0·4	12·6	0·4	13	1	0	0
16-31	40·9			0·7	36·0		0·4		45·2	0·7	36·0	0·4	29	22	6	4
Feb. 1-15	25·1			0·4	14·4			0·3	25·4	0·5	15·7	0·5	13	1	3	6
16-28	34·7			0·7	26·6		0·3		34·7	0·7	26·6	0·3	15	9	5	1
Mar. 1-15	29·2			0·3	14·7			0·1	33·8	0·4	14·9	0·5	21	2	0	1
16-31	30·5			0·6	19·3		0·5		30·7	0·6	19·6	0·6	16	4	2	2
April 1-15																
16-30																
May 1-15																
16-31																
June 1-15																
16-30																
July 1-15																
16-31																
Aug. 1-15																
16-31																
Sept. 1-15																
16-30																
Oct. 1-15																
16-31																
Nov. 1-15																
16-30																
Dec. 1-15																
16-31																
TOTALS ..	189·7			2·9	122·0		1·3	0·4	199·1	3·3	125·4	2·7	107	39	16	14
MEANS ..	+31·6		−0·5		+20·3		+0·2		33·2	0·6	20·9	0·5				

Observations discontinued from 1st April 1931, when the tidal observatory was dismantled. See Geodetic Report, Vol. VII, page 32.

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* E_1 is with regard to sign: E_2 is without regard to sign.

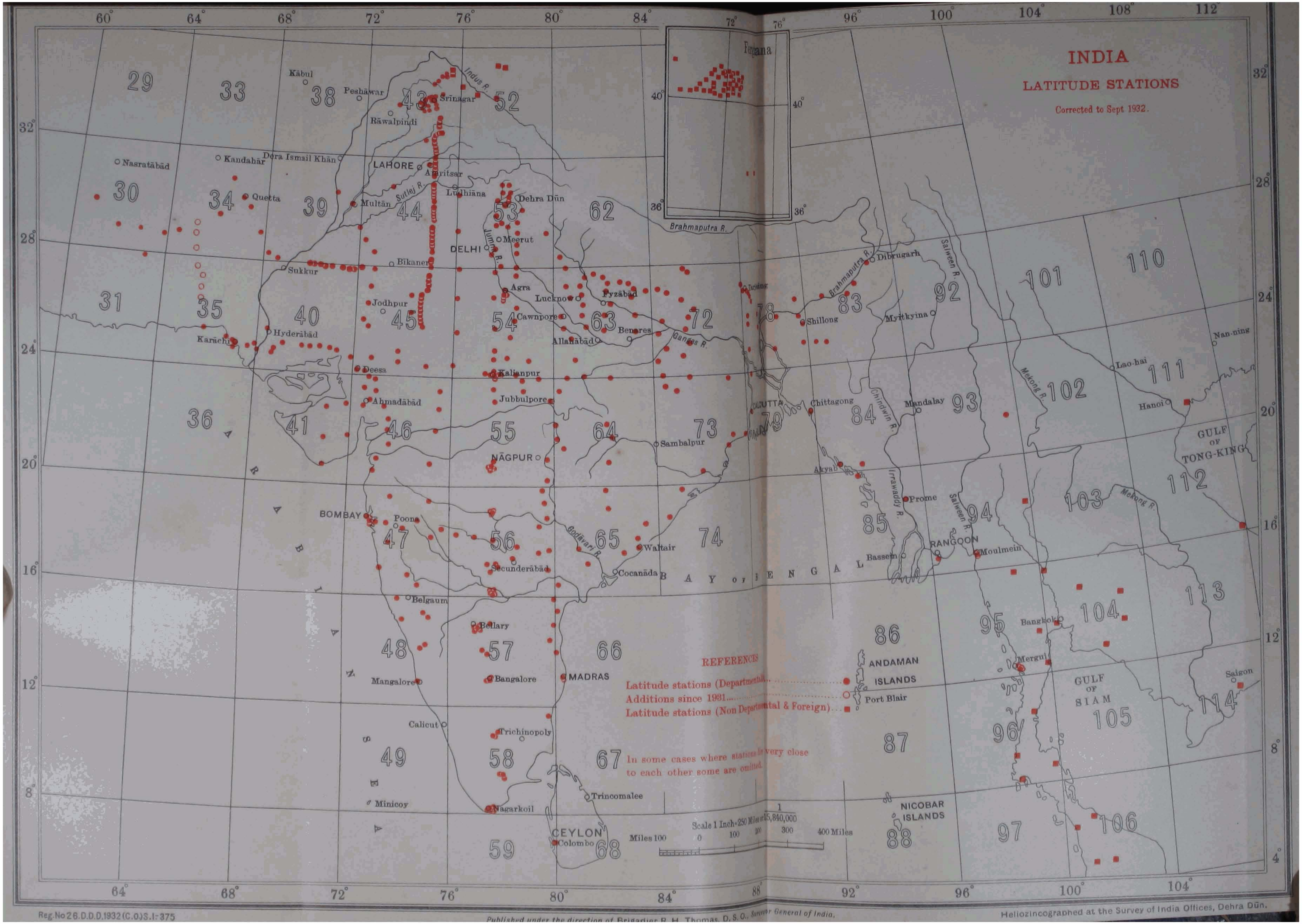
† Actual values are tide-pole readings taken at Pilakāt Creek, about 800 feet up the site of predictions for Elephant Point of 1884-88, which latter is again about 2 miles up that of Elephant Point of 1880–81.

TABLE 17. *Mean errors E_1* and E_2* for 1931.*

RANGOON

PERIOD 1931	MEAN ERRORS (Predicted – actual)												Number of errors exceeding			
	E_1*								E_2*				30 minutes of time		1·0 foot of height	
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.	H. W.	L. W.	H. W.	L. W.
	minutes		feet		minutes		feet		minutes	feet	minutes	feet				
	+	−	+	−	+	−	+	−								
Jan. 1-15	2·6		0·3			5·3	0·3		5·0	0·4	15·7	0·6	0	0	1	4
16-31	6·8			0·1	7·3		0·5		9·0	0·3	14·7	0·5	1	2	0	5
Feb. 1-15	1·0		0·2			2 8		0·2	8·1	0·5	14·3	0·6	0	1	3	6
16-28	6·4			0·1	8·0		0·2		10·4	0·3	11·0	0·3	1	1	0	1
Mar. 1-15	1·8		0·4			3·8		0·1	11·2	0·6	12·4	0·5	3	1	5	2
16-31	5·3		0·2		7·5		0·5		9·4	0·3	11·8	0·6	0	2	0	1
April 1-15		0·2	0·4			2·9		0·3	13·1	0·5	11·2	0·5	2	1	4	5
16-30		1·4	0·1		3·8		0·3		5·9	0·3	11·9	0·5	0	1	0	3
May. 1-15		0·3	0·1		2·0			0·5	9·2	0·4	11·5	0·8	2	2	0	10
16-31	1·2		0·0			0·7		0·1	5·0	0·5	12·9	0·5	0	0	1	2
June 1-15	5·3		0·1		7·6			0·1	8·9	0·2	13·8	0·5	1	0	0	2
16-30	3·0		0·2		2·1		0·2		7·3	0·4	11·2	0·5	0	0	0	5
July. 1-15	8·3			0·0	14·4			0·0	12·8	0·4	19·0	0·4	3	3	0	2
16-31	4·3		0·3			2·6	0·4		7·2	0·4	14·3	0·5	0	0	4	5
Aug. 1-15	8·3		0·2		8·7		0·2		10·6	0·4	13·0	0·4	1	1	0	1
16-31	13·5			0·3	3·2			0·7	15·6	0·5	11·3	0·8	0	0	1	10
Sept. 1-15	13·6		0·4		7·3		0·3		18·0	0·5	13·6	0·4	3	2	6	0
16-30	2·6		0·3		3·4		0·9		11·0	0·5	7·7	0·9	1	0	1	13
Oct. 1-15	8·9		0·2		6·2		0·3		11·6	0·5	11·4	0·7	1	2	2	6
16-31		1·3	0·3		6·8		1·0		10·3	0·4	9·9	1·0	3	0	0	12
Nov. 1-15	2·7		0·6		1·4		0·7		8·9	0·6	13·1	0·8	0	1	6	8
16-30	7·2		0·2		8·6		0·6		10·2	0·3	14·2	0·8	0	0	1	8
Dec. 1-15	4·3		0·6			2·1	0·8		6·7	0·6	15·0	0·8	0	1	0	7
16-31	4·2		0·1		7·2		0·1		6·3	0·4	15·6	0·4	0	1	0	1
Totals ...	111·3	3·2	5·2	0·5	105·5	20·2	7·3	2·0	231·7	10 2	310·5	14·3	22	22	35	11
Means	+ 4·5		+ 0·2		+ 3·6		+ 0·2		9·7	0·4	12·9	0·6				

* E_1 is with regard to sign: E_2 is without regard to sign.



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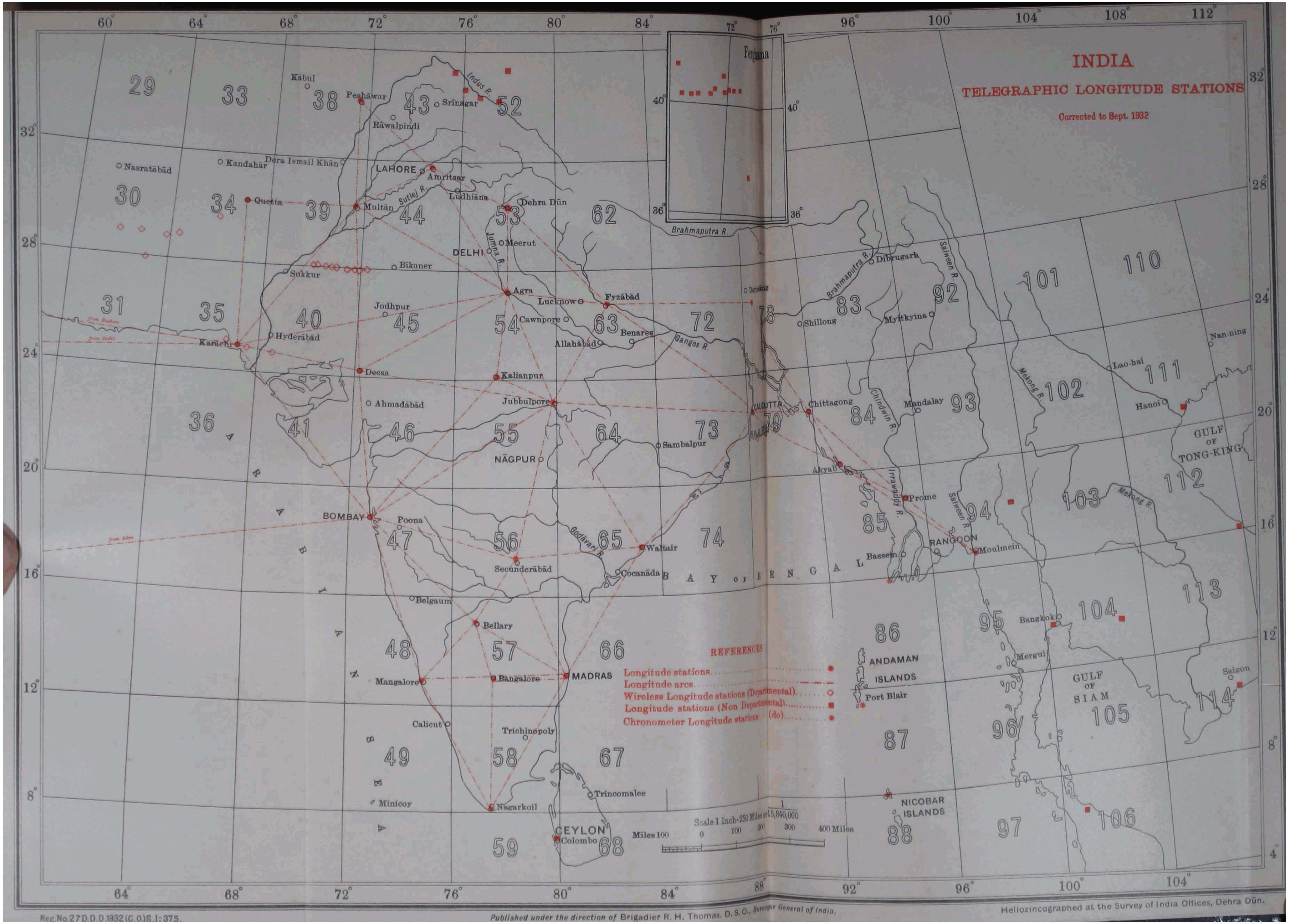

INDIA

TELEGRAPHIC LONGITUDE STATIONS

Corrected to Sept. 1932

Reg. No. 27 D.D.D. 1932 (C.O.) S.I.: 375.

Published under the direction of Brigadier R. H. Thomas, D.S.O., Surveyor General of India.

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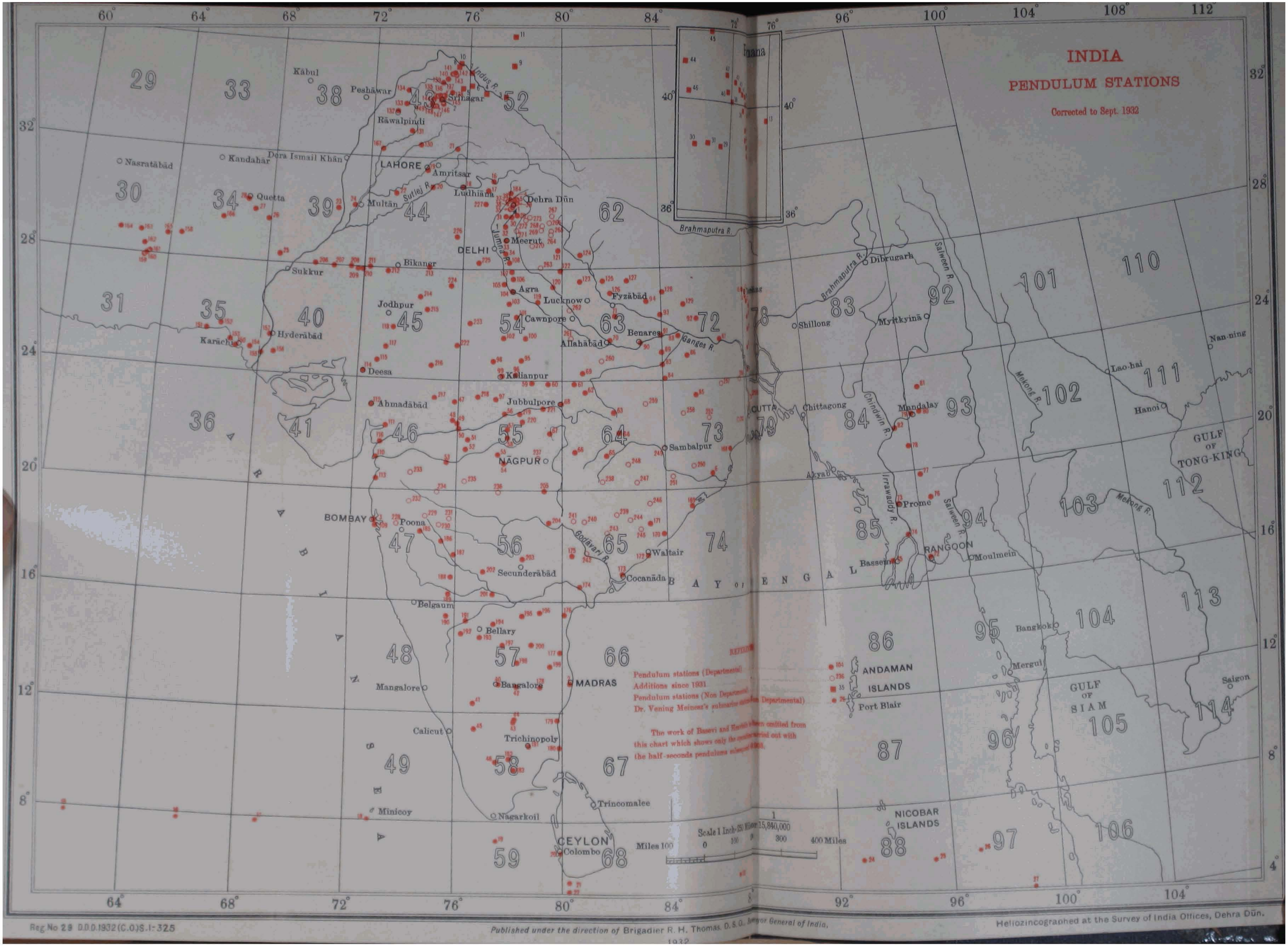

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CHAPTER IV

GRAVITY

BY MAJOR E. A. GLENNIE, D.S.O., R.E.

(i) FIELD SEASON 1931–32

1. Programme. This field season, the party was equipped with two 1½-ton Ford Motor Trucks, hired for the whole season. As a result of having fast transport always at hand, a very full programme was possible.

Starting from Bombay, the party zigzagged right across India through Calcutta to Jessore, putting in 27 gravity stations on route, and then, turning north-west, observations were made at 19 more stations in the plains and hills. Chart III shows the location of these stations. The total mileage amounted to 5,800 miles. No mechanical troubles of any sort occurred. A considerable distance was over temporary roads or rough cart tracks in remote areas; the lorries were frequently stuck in soft sandy patches in the rivers and a good deal of rough pioneering had to be done. On one occasion it took eight hours to traverse three miles.

Observations were made in rooms wherever possible, but the pendulum tent was frequently used.

2. Strength of the party. In order to carry the whole party with its equipment in two light lorries, great reduction had to be made in the establishment; one clerk, two computers and three khalāsis were left behind in a headquarter's camp at Dehra Dūn, and the party which took the field consisted of one officer, five khalāsis, two drivers, two cleaners and two private servants. This party fitted in the lorries quite comfortably without overloading. The inconveniences due to the very small establishment were more than compensated for by the great advantages of motor transport. Practically the whole party contracted malaria while in the Orissa Hill States, otherwise health was good.

3. Method of observation. The method of observation was the same as in the previous two field seasons. Except in the Calcutta neighbourhood, and in April, wireless time signals were loud and clear. Within a radius of 100 miles of Calcutta wireless conditions were exceedingly bad, and at Barrackpore, only the night signals could be heard and those only with difficulty Jessore was nearly as bad. To get over this difficulty the Nauen signal received at 5.30 a.m. Indian Standard Time was taken. This signal proved so convenient that it was used throughout the latter end of the field season, leading to a speeding up of the programme.

The normal programme with this signal was:

1st day	3.30 p.m. ...	Rugby signal: start pendulums.
	11.30 p.m. ...	C and A. Complete 1st measure and commence second measure.
2nd day	5.30 a.m. ...	Nauen signal: complete 2nd measure and commence 1st measure of pendulums A and B.
	3.30 p.m. ...	Rugby signal: complete 1st measure and commence 2nd measure.
	11.30 p.m. ...	Rugby signal: observations completed.

It was frequently possible to finish work at one place at 11.30 p.m., and commence work a hundred miles away at 3.30 p.m. on the next day.

A further change in procedure is in contemplation whereby all observations at a place can be fully completed in 24 hours.

An objection to the use of the Nauen 5.30 a.m. signal is that the corrections for this signal are not published in Admiralty Notices nor in the Bulletin Horaire. The German publication has to be obtained.

The automatic warning now sent out before the Rugby time signal is a great boon and is all that is required. It consists of the code GBR GBR GBR TIME repeated four times, beginning 45 seconds before the time signal and ending 20 seconds before it.

Bad wireless reception in April near the hills appears to be due to thunder clouds situated close to the hill tops. A thunder cloud away from hills does not have an adverse effect on wireless reception, except for the harsh crack when an actual lightning discharge occurs.

Two Mercer chronometers were used throughout the field season for all observations, but the rate of one chronometer (Mercer No. 13560) proved so erratic that the observations made with it have not been included in the final results, except at places where wireless reception was bad. Nevertheless in spite of the erratic rate, amounting at times to a change in the 24-hourly rate of eight seconds in a period of less than eight hours, the results obtained with the bad chronometer are practically identical with those obtained with the good one. This is because the programme is so arranged that the pendulum swings nearly continuously between time signals. Erratic rate variations do however have some effect during the three quarters of an hour occupied in changing pendulums. Hence observations with the bad clock have not the same weight as those made with the good one.

PLATE IV.

TEMPORARY BRIDGE IN BASTAR STATE.

WELL DOWN.

At Barrackpore, before observations were commenced, the pendulums were left hanging still on the agates for an hour, to see if there was any sign of ground motion, but none was detected. It is a feature of the Cambridge apparatus that even if there is ground motion the mean time of vibration of the two pendulums when observed simultaneously is practically unaffected by the motion. If however the ground is found to be in motion, the two pendulums should not be swung in optical combination. It will then be possible to apply a correction for the small residual effect of the ground motion on the mean time of vibration of the pair of pendulums.

4. Results. The results are shown in Tables 1 to 4. Table 2 shows good agreement between pairs of pendulums except where marred by bad wireless reception.

(ii) RESEARCH WORK

5. Standard Gravity Formula. A standard gravity formula suited to the International spheroid has been adopted at the Stockholm meeting of the International Geodetic Union in 1930. The formula is:

$$\gamma_{OI} = 978 \cdot 049 \ (1 + 0 \cdot 005288 \sin^2 \phi - 0 \cdot 000006 \sin^2 2\phi)$$

where ϕ is the latitude. The Helmert 1901 formula has hitherto been recognized as the standard. This is:

$$\gamma_{OH} = 978 \cdot 030 \ (1 + 0 \cdot 005302 \sin^2 \phi - 0 \cdot 000007 \sin^2 2\phi)$$

Any value of γ_{OH} can be readily changed so as to obtain the value corresponding to another spheroid X with equatorial gravity G'_x by the following relation:

$$\gamma_{OX} = \gamma_{OH} + \Delta_{SX} + (G'_x - 978 \cdot 030).$$

Similarly any anomaly A_H obtained with the Helmert formula can be converted by the expression:

$$A_X = A_H - \Delta_{SX} - (G'_x - 978 \cdot 030).$$

Values of Δ_S are given in Charts V and VI for the International spheroid and for the S. of I. No. II spheroid. In the case of the Standard International formula the value of the constant term $(G'_I - 978 \cdot 030)$ is $+0 \cdot 019$ cm/sec².

Hayford anomalies $(g - \gamma_{OI})$ obtained with the new standard formula are given in Chart VII. It will be obvious from what follows that the new formula yields anomalies which are less suitable for India than those obtained with the Helmert 1901 formula. This is mainly due to the high value of G'_I adopted. A more suitable value for India for use with the International spheroid is 978·017 cm/sec² (see Geodetic Report Vol. V, page 56).

6. Crustal warpings and geology. Last field season's work has provided large additions to the gravity data in India, and has also resulted in some important alterations in the anomaly contours drawn previously in areas where the data was scanty

In addition to this, the new edition of the Geological Map of India has just been published. It is therefore proposed to examine the conclusions reached at the end of last recess (Sept. 1931) in detail, so as to see how far they are justified in the light of the more recent geological and gravity data.

In Professional Paper No. 27 (1932) it has been claimed that gravity anomalies are mainly due to deep-seated crustal warpings. If the warp is gentle and widespread it may not be indicated on the surface of the land by any obvious geological or topographical features. Other more abrupt and less widespreading warps may be indicated on the surface by special features. The $g - \gamma_F$ anomaly developed in Professional Paper No. 27 is intended to portray these small warpings. Briefly the $g - \gamma_F$ anomaly has been derived from the Hayford anomaly by removing the effect of the widespread and gentle warpings (Hidden Range) and by a correction necessitated by the actual lack of isostatic compensation. Since the S. of I. Spheroid II is the spheroid best suited to India, the $g - \gamma_F$ anomalies will be referred to it. Comparison will be made with the Hayford anomalies ($g - \gamma_{CH}$) using the Helmert formula (see Charts VIII and IX) since it would be unfair to the isostatic hypothesis to use the unsuitable new standard formula for the purposes of this comparison.

A crustal up-warp will not necessarily be visible on the surface as an elevation. The movement may be so gradual that denudation keeps pace with it. First the most recent geological formations will vanish through denudation, and then the older, until finally in the older or greater up-warps the fundamental igneous rocks will be exposed.

Exposures of certain typical igneous rocks may therefore be accepted as definite indications of crustal up-warps. Small local exposures of volcanic or effusive rocks may also be taken as evidence of crustal up-warps close by, but not necessarily at the actual site of the outcrop, since the rocks may have come through fissures or failures of the lower slopes of the up-warp, or may have spread over adjacent down-warped areas.

The Deccan trap is a vast sheet of rock covering both up-and-down-warps of the crust, and only definitely associated with an up-warp at the main focus (or foci) of effusion.

A crustal down-warp naturally provides a basin for the accumulation of sediment, and if the down-warp is slow, sedimentation will keep pace with it—that is, in land areas where there will be an up-warp nearby to provide the sediments. Sedimentary deposits will therefore be found in the down-warped areas, but the sedimentary origin of the rocks may be concealed by metamorphic action, and they are then grouped in the geological map under the head "unclassified crystallines, gneiss etc." which includes rocks of either sedimentary or igneous origin.

As already indicated above, sedimentary rocks may be found on up-warped areas where the elevation has been either too small or too recent for their complete removal by denudation. Generally speaking one would expect down-warps underlying the broader sedimentary formations, such as the main exposures of the Vindhyans and Cuddapahs.

The broad alluvial plains of Northern India are in a separate category, they overly and flank a crustal area still in active movement, and like the Deccan trap, conceal both up-warps and down-warps of the crust.

From the above considerations, the following conclusions are reached:

(*i*) The fundamental igneous rocks (granite, syenite, charnockite and khondalite) definitely indicate crustal up-warps.

(*ii*) Sedimentary formations and unclassified crystallines are indefinite. Their situation with reference to group (*i*) will provide a clue.

(*iii*) Volcanic rocks and small patches of effusive rocks indicate a crustal up-warp nearby, but not necessarily at the site of the exposure.

(*iv*) Deccan trap and alluvium conceal the nature of the crustal warps underlying them.

Chart X is a geological sketch map adapted from the new Geological Map of India. The above four groups are shown in it as follows:

Group I Red.
II Sediments .... Blue, unclassified crystallines .... pink.
III Red and green.
IV Deccan trap .... green, Alluvium and unclassified areas .... white.

7. $g-\gamma_F$ and the igneous rocks of Group I. If the igneous rocks of Group I definitely indicate a crustal up-warp, $g-\gamma_F$ must be positive over these areas, and stands or falls according to its success in showing them.

I. East coast and Southern India.

Commencing near Cuttack and extending down the East coast of India to South of Madras and then turning west across India roughly along Lat. 12° is a very striking belt of igneous rocks.

This is very well demarcated by the $g - \gamma_F$ anomalies. There are sixteen gravity stations in this area and of these fifteen yield positive anomalies averaging + 0·020 cm/sec^2. One only is negative (No. 171 Pārvatīpuram, $g - \gamma_F = -0 \cdot 007$, $g - \gamma_{CH} = -0 \cdot 009$). The Hayford anomalies ($g - \gamma_{CH}$) fail to show the feature. Only five of the sixteen anomalies are positive.

The negative $g - \gamma_F$ anomaly at Pārvatīpuram appears to be associated with a very small positive anomaly at Dusi (No. 170, $g - \gamma_F = +0 \cdot 001$, $g - \gamma_{CH} = -0 \cdot 005$). If so, the peculiarity disclosed at Pārvatīpuram is not purely local.

II. A large exposure of syenites roughly along Long. 77° from Lat. 12° to 15° with other smaller outcrops to the west.

All $g - \gamma_F$ anomalies in this area are positive, all Hayford anomalies are negative (5 stations average $g - \gamma_F = +0 \cdot 011$, $g - \gamma_{CH} = -0 \cdot 027$).

III. A large outcrop of granite about Lat. 20° Long. 80°.

There is no gravity station on this exposure, but on the unclassified crystalline rocks to the south observations at Bhopālpatnam gave a remarkably high positive anomaly ($g - \gamma_F = +0 \cdot 044$, $g - \gamma_{CH} = +0 \cdot 033$). Evidently high positive anomalies are to be expected over these granites.

IV. Granite and volcanic rocks WNW. of Calcutta near Purūlia and Sūri and SW. of Daltonganj.

All this area is strongly positive (Sūri $g - \gamma_F = +0 \cdot 061$, $g - \gamma_{CH} = +0 \cdot 053$, Daltonganj $g - \gamma_F = +0 \cdot 024$, $g - \gamma_{CH} = +0 \cdot 013$).

The general run of the anomaly contours indicates an extension of this positive area to the similar igneous area south of Shillong.

V. Bundelkhand Granite.

Stations on this area are:

No.	Station	$g-\gamma_F$	$g-\gamma_{CH}$
100	Jhānsi ...	+0·014	+0·014
261	Bānda ..	+0·016	+0·013
95	Lalitpur ...	−0·014	−0·002

Lalitpur is near the southern boundary of the exposure.

VI. Igneous rocks of the Arāvalli Hills and to the NE. in the same line towards Delhi.

All $g - \gamma_F$ anomalies in this region are strongly positive except Degāna which is somewhat west of the line.

The stations are:

No.	Station	$g-\gamma_F$	$g-\gamma_{CH}$
114	Deesa ...	+0·040	+0·047
115	Abu ...	+0·012	+0·020
117	Erinpura ...	+0·011	+0·020
118	Pāli Mārwār ...	+0·013	+0·021
215	Ajmer ...	+0·050	+0·062
224	Rīngas ...	+0·044	+0·044
225	Rewāri ...	+0·031	+0·012
214	Degāna ...	−0·021	−0·016

VII. Igneous rocks of Baluchistān.

There are no gravity stations in the igneous area. A positive $g - \gamma_F$ anomaly (+0·023) is found at Warechah which is near the Koh-i-Taftān volcano and where there are rocky outcrops.

The $g - \gamma_{CH}$ anomaly is positive at Warechah also, but the Hayford anomalies are also positive over most of the light deep alluvium of the Hāmūn-i-Māshkel depression. This is certainly a depressed area and so positive anomalies are unsatisfactory. The $g - \gamma_F$ anomalies over this depression are all negative.

VIII. Igneous rocks of the outer Himālaya.

All along the outer Himālaya small patches of granite, and in Kashmīr Tertiary volcanic rocks as well as granite are shown in the Geological Map. Positive anomalies ($g - \gamma_F$ and $g - \gamma_{CH}$) are found.

Summing up the foregoing, eight igneous areas have been cited. In all of these the $g - \gamma_F$ anomaly is predominantly positive. The Hayford anomaly is equally positive in many of the areas, but it is negative in the two largest and most strongly defined areas.

Out of a total of 41 stations in these areas, the anomalies give the following numbers :

	Positive	Negative
$g - \gamma_F$ ...	38	3
$g - \gamma_{CH}$ ...	23	18

8. $g - \gamma_F$ and the Cuddapah system. The great basin of Cuddapah sediments north-west of Madras is exactly defined by the $g - \gamma_F$ anomalies. These are all negative. The Hayford anomalies are negative too, but they are also negative over all the surrounding igneous rocks, so that no clear distinction between the two types of area is obtained, as is the case with the $g - \gamma_F$ anomaly.

The $g - \gamma_F$ anomalies show that in this area the crustal layers are depressed. D. N. Wadia (*Geology of India,* p. 72) says, "To account for the enormous thickness of the Cuddapah sediments " ....it is necessary to suppose that a slow and quiet sub- " mergence of the surface was in progress all through their deposition, " which lowered the basins of sedimentation as fast as they were " filled."

Another large area of the same system is to be found about Lat. 22° Long. 82° around Jagdalpur. The crystalline rocks in Bastar state are very strongly banded and may be assumed to be sedimentary in origin. All the anomalies in these large areas are negative indicating a crustal depression. The Hayford anomalies fail to demarcate the area, being positive in the northern part near Bilāspur over the sediments, and negative in the south over the adjacent igneous areas.

9. $g - \gamma_F$ and the Dharwar sytem. The outcrop of Dhārwār rocks near Sawai Mādhopur, and to the south-west of this place, evidently occupies part of the same great basin as the Vindhyans, but other outcrops of this system have been caught up by the rejuvenation of the Arāvalli Hills and its more recent extension northwards, (see Professional Paper No. 27, Chart IV, transverse crest lines 2 and 3).

In this connection two errors in Professional Paper No. 27 require correction. Firstly Sawai Mādhopur is wrongly stated to be a typical Vindhyan Station (Professional Paper No. 27, p. 15) and secondly the rejuvenation of the Arāvalli Hills is ascribed to a recent period, (Professional Paper No. 27, p. 21). Actually the rejuvenation was contemporary with the depression of the Vindhyan basin. These corrections affect minor details only and are not in any way adverse to the conclusions reached in Professional Paper No. 27.

Station No. 252 Chaibāsa is on an outcrop of the Dhārwār system ; here $g - \gamma_F = -0\cdot005$, $g - \gamma_{CH} = +0\cdot007$.

Other exposures of the Dhārwār system are usually associated with igneous outcrops and evidently overly crustal up-warps, so that the $g - \gamma_F$ anomalies are positive. Denudation following the uprise has left only the narrow bottoms of the synclinal folds (see Wadia : *Geology of India,* p. 61).

10. $g - \gamma_F$ and the Vindhyan system. Quoting Wadia (*Geology of India,* p. 77), the Vindhyan system "occupies a large "extent of the country—a stretch of over 40,000 square miles— "from Sasarām and Rohtas in western Bihār to Chitorgarh on the "Arāvallis, with the exception of a central tract in Bundelkhand. "The outcrop has its maximum breadth in the country between Agra "and Neemuch." Except at Sīpri, near the outcrop of Bundelkhand granite, and in the extreme north-east, all this area shows negative anomalies.

The stations are :

No	Station	$g - \gamma_F$	$g - \gamma_{CH}$
216	Nīmach ...	−0·024	−0·004
222	Kotah ...	−0·007	+0·003
102	Sīpri ...	+0·020	+0·029
223	Sawai Mādhopur ...	−0·025	−0·021
60	Damoh ...	−0·009	+0·004
69	Maihar ...	−0·013	−0·003
260	Mangawān ...	+0·008	+0·015
89	Sasarām ...	+0·026	+0·009

The stations which show positive $g - \gamma_F$ anomalies are those which have been involved in the uprise of the second crest of the Hidden Range (see Professional Paper No. 27, p. 21 and Chart IV).

The Vindhyan system evidently overlies a deep crustal downwarp, a large part of which is concealed by the Deccan trap.

11. $g - \gamma_F$ and the Gondwana system. Again quoting Wadia (*Geology of India* pp. 113–14). "Three large tracts in "the Peninsula can be marked out as prominent Gondwāna areas : "(1) a large linear tract in Bengal along the valley of the Dāmodar "river with a considerable area in the Rājmahāl hills ; (2) an "expansive outcrop in the Central Provinces prolonged to the south-"east in a belt approximately following the Mahānadi Valley ; (3) a "series of more or less connected troughs forming an elongated band "along the Godāvari river from near Nāgpur to the head of its "delta." There is also (4) an area around Pachmarhi and (5) areas in Kāthiāwār, Cutch and Jaisalmer.

Stations in these areas are listed below:

Area	No	Station	$g-\gamma_F$	$g-\gamma_{CH}$
(1)	257	Dhānbād ...	+0·021	+0·019
	84	Daltonganj ...	+0·028	+0·025
(2)	259	Ambikāpur ...	−0·023	+0·002
	63	Pendra ...	−0·015	+0·008
(3)	205	Chānda ...	+0·001	−0·002
	175	Yellandlapād ...	+0·009	−0·013
(4)	220	Pachmarhi ...	−0·044	−0·044
(5)	...	No gravity stations ...	...	...

Areas (2) and (4) present no difficulties. Chart IX shows that they form part of an extensive down-warp.

An explanation will now be sought for the positive $g-\gamma_F$ anomalies in area (1). The same explanation will perhaps serve for area (3), though more stations are required for the proper elucidation of this area. D. N. Wadia (*Geology of India*, pp. 110–11) says: "The Gondwāna system is in many respects "a unique formation ....the peculiar mode of its deposition "in slowly sinking faulted troughs............ stamp these rocks with "a striking individuality among the geological systems of India "............ The formation of thousands of feet of river and stream "deposits cannot be explained in any other supposition........... It "is suggested that the mountain-building and other crustal move-"ments of an earlier date had their reaction now in the subsidence "of large blocks of the country to the equilibrium-plane, between "vertical or slightly inclined fissures in the crust." If this explanation is correct, the crustal warp theory requires that the $g-\gamma_F$ anomalies should be negative; but quite another explanation is possible, which appears to fit the facts better. The Gondwāna deposits of Bengal are associated with dykes of ultra-basic igneous rocks (Wadia: *Geology of India*, p. 119) and outcrops of igneous rocks occur nearby. The area is in fact one of crustal up-warp, not subsidence (see para 7). There has been vertical pressure from below upwards. Rifts due to tension have developed in the Archæan crystalline rocks, and in these the Gondwāna sediments have accumulated. Widening of the rifts due to continued pressure from below and increasing tension led to down-faulting of these sediments. This solution of the problem explains the positive anomalies. The explanation is the same as that given in Professional Paper No. 27, p. 25, for positive anomalies over deeps in the Java Seas.

12. $g-\gamma_F$ and the sedimentary areas of the Himālaya. The Purāna sediments and Siwāliks overlie the up-warp of the crust referred to in para 7. $g-\gamma_F$ anomalies are therefore positive.

No.	Station	$g-\gamma_F$	$g-\gamma_{CH}$
5	Mussoorie ...	+0·072	+0·053
1	Dehra Dūn ...	+0·034	+0·006
35	Mohan ...	+0·040	+0·003

North of this outer up-warp negative gravity anomalies indicate the deep down-warp under the folded sedimentary mountains of the Inner Himālaya.

The abrupt fall is shown well by the anomalies:

No.	Station	$g-\gamma_F$	$g-\gamma_{CH}$
143	Deosai III ...	+0·054	+0·095
	Wozul Hadur ...	+0·002	+0·036
	Skārdu ...	−0·015	+0·015
	Depsang ...	−0·075	−0·064

Deflection data available confirm these conclusions. The geoid rises over the outer up-warp and then falls steadily until the axis of the down-warp is reached. The deflection at Depsang is small (about 2″ to the NE.) indicating that this station is just on the northern side of the down-warp. Capt. G. T. McCaw voices a common but erroneous impression in the South African Survey Journal (April 1932, p. 97) when he says, "the geoid would still tend to follow "the surface configuration, just as it persists in rising under the "Himālaya." Data in India show that the geoid has no tendency to follow the surface configuration.

13. $g-\gamma_F$ and the Deccan trap. The Deccan trap is a great sheet concealing the underlying crustal structure. Gravity investigations form the only economically feasible method of discovering this structure. After making a detailed examination of the Deccan trap area with pendulums, it should be possible to select areas where deep borings would be a profitable speculation.

The first part of field season 1931–32 was devoted to the rough delineation of the crustal down-warp underlying the trap, which had been disclosed by the negative gravity anomalies at Dhond and Kurduvādi. The down-warp has been found to be much more extensive than was previously expected, and has led to considerable changes in the anomaly contours east and north-east of Bombay. The following stations overly this down-warp:

No.	Station	$g-\gamma_F$	$g-\gamma_{OH}$
186	Kurduvâdi ...	−0·012	−0·041
185	Dhond ...	−0·015	−0·039
228	Talegaon ...	−0·023	−0·048
230	Jâmkhed ...	−0·003	−0·021
232	Sangamner ...	−0·018	−0·020
233	Satâna ...	−0·034	−0·035
234	Daulatâbâd ...	−0·008	−0·014
235	Chikli ...	−0·014	−0·015
236	Pusad ...	−0·003	−0·009

The large negative $g-\gamma_F$ anomaly at Satāna probably does not imply an increased depth in the down-warp there, but rather a decrease in thickness of the trap. The gravity effect of 450 feet of trap (density 2·83) is +0·001 cm/sec^2; if, therefore, there is 9,000 feet of trap at Talegaon, the effect due to the down-warp there must be −0·043 cm/sec^2, whereas at Satāna, if the trap is only 1,800 feet thick, the effect of the down-warp will be −0·039 cm/sec^2.

In the north it is unlikely that this down-warp extends into the Vindhyan down-warp north of the Narbada river; it is more probable that it is closed by an up-warp along the line of the Sātpura Range. All gravity observations so far made on this range have yielded positive anomalies. Geological evidence is also in favour of an up-warp here (see Wadia: *Geology of India,* p. 12).

More gravity stations are required to define the western boundary of down-warp. The very abrupt change from negative to large positive anomalies between Talegaon and Bombay strengthens the opinion already formed that there has been a fracture of the crust near Bombay and that there is to be found the main focus of effusion of Deccan traps (see Professional Paper No. 27, p. 16 and Fig. 4).

14. $g-\gamma_F$ and the Indo-Gangetic alluvium. Like the Deccan trap, the alluvium conceals the nature of the underlying crustal structure. If there is an up-warp of the crust, under the alluvium, so gradual that the denudation at the surface keeps pace with it, there will be little or no indication of the up-warp until the rocks underlying the alluvium are raised to the surface. The $g-\gamma_F$

anomalies show an up-warp under the Punjab alluvium. A very recent up-warp, probably still proceeding extends south-west from midway between Sahāranpur and Ambāla to the Arāvalli Hills. Surface indications of this up-warp may be found in recent changes in the direction of the rivers in the Punjab. The axis of this up-warp is the watershed, on the northern plain, between the river systems of the Arabian Sea and the Bay of Bengal.

A similar up-warp under the alluvium is shown by the anomalies south of Darjeeling; this up-warp is still progressing and is shown by a gradual rise in level in this area relative to Howrah where tidal observations show no change of level (see Geodetic Report Vol. VI, p. 104 *et seq.*)

Last season's work has straightened out the southern boundary of the "Gangetic Trough". The southerly extension of the trough south of Lucknow in the Chart of Hayford anomalies in Geodetic Report Vol. VII is removed. The second crest of the Hidden Range (see Professional Paper No. 27 Chart IV) is now very clearly defined by the $g - \gamma_F$ anomalies. The "Gangetic trough" is probably merely a shallow relic of the Tethys basin which has escaped the recent orogenic movements.

15. The crustal structure lines of India. $g - \gamma_F$ anomalies disclose two systems of crustal structure lines in India:

(1) An ancient and somewhat intricate mesh of up-and-down-warps in the peninsular area.

(2) Imposed on this and to the north are the broad sweeping lines of the later Hidden Range--Tethys movement. The simple character of the mesh of this last system is a sign of its juvenile and unstable nature.

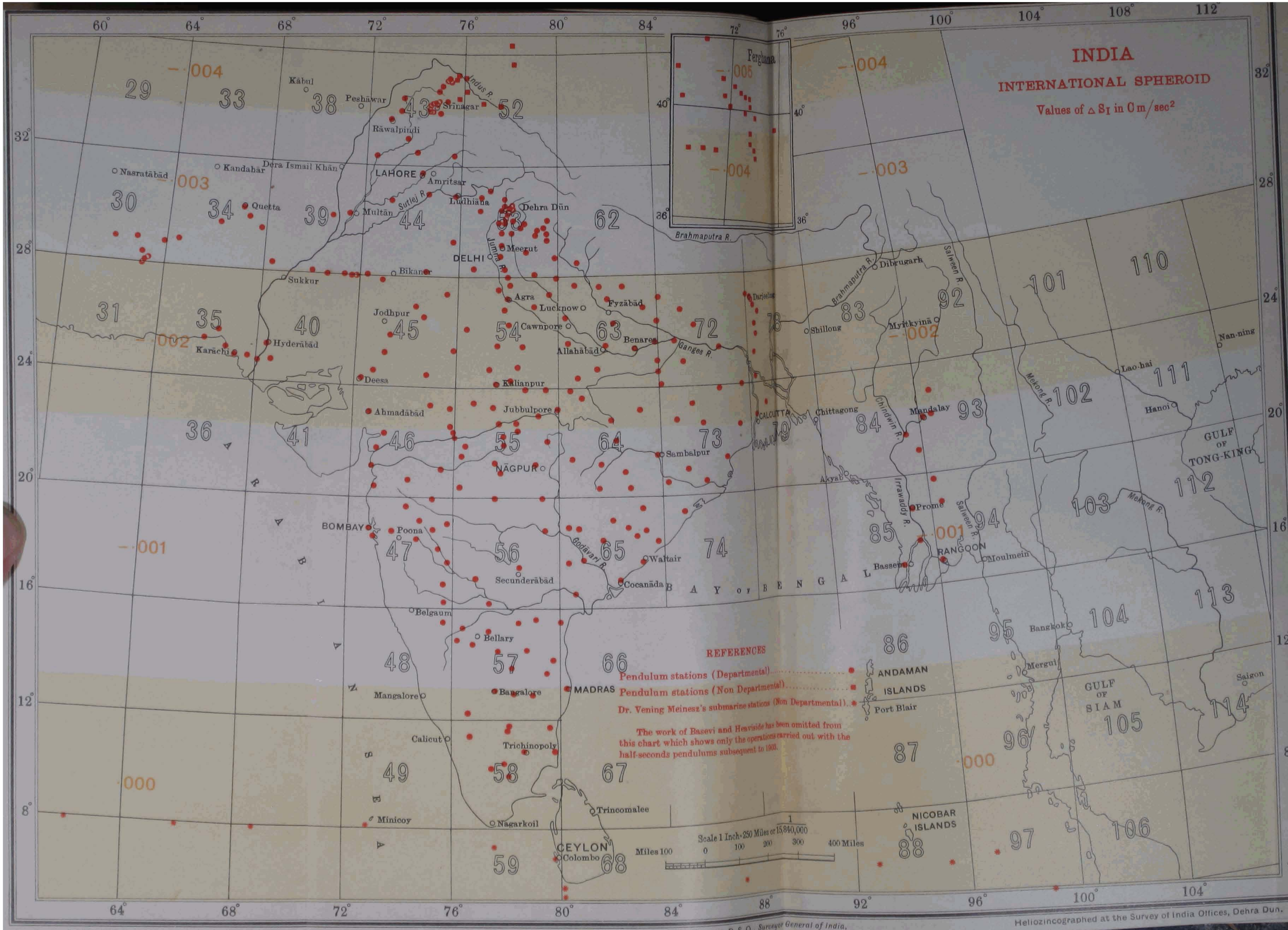
These structural systems are shown in Chart XI.

Dr. F. A. Vening Meinesz has shown the structural lines in the Indian Archipelago. His gravity values connote an up-warp of the crust underlying Java and Sumatra, flanked by a down-warp to the south and west, and he says, "it seems likely that the "Ganges valley anomalies are the continuation of the negative strip "of the Indian Archipelago". Chart XI is opposed to this conclusion, it is more probable that the Sumatra down-warp will follow the curve of the Nicobar and Andaman Islands and continue under the folded sediments of the Arakan Yoma Range, perhaps ultimately connecting with the northernmost trough line shown on Chart XI.

A continuation of the geoid eastwards across Burma from India would go far to settle this problem.

16. Conclusion. Theoretically, gravity can give no clue to the distribution of mass in the earth's crust (see McCaw, *South African Survey Journal*, April 1932 p. 97), but this is only the case if other geological and geophysical data are ignored. If data from deflections, geology and earthquakes are used together with a considerable mass of gravity data, the field of possible solutions of the crustal distribution of mass is narrowed down enormously,—possibly to a unique solution.

Gravity work is being carried on with increasing enthusiasm by practically all civilized nations in every part of the world, and is rapidly leading to a good understanding of the crustal processes of the earth. While being international in outlook, Indian gravity work is of great local importance. The preliminary programme of gravity work is restricted to the more or less uniform spacing of gravity stations about seventy miles apart all over the Indian area. The uncoloured spaces on Chart IX show work yet to be done. Assam is untouched and Burma nearly so, and in Burma too deflection data are required before the gravity work there can be used with confidence. Some gravity work in Ceylon will be necessary for the proper understanding of the rather baffling conditions in the extreme south of India. The crustal structure disclosed by the preliminary gravity programme will be a guide to geologists, not only in areas covered by alluvium and Deccan trap, but also in other areas where the superficial geological data are puzzling. After this, detailed gravity survey of selected areas, aided by geological experts, will be only a short preliminary to the commercial exploration of promising localities.



INDIA

INTERNATIONAL SPHEROID

Values of Δg_I in cm/sec^2

REFERENCES

Pendulum stations (Departmental)........................ ●

Pendulum stations (Non Departmental)........................ ■

Dr. Vening Meinesz's submarine stations (Non Departmental).. ✱

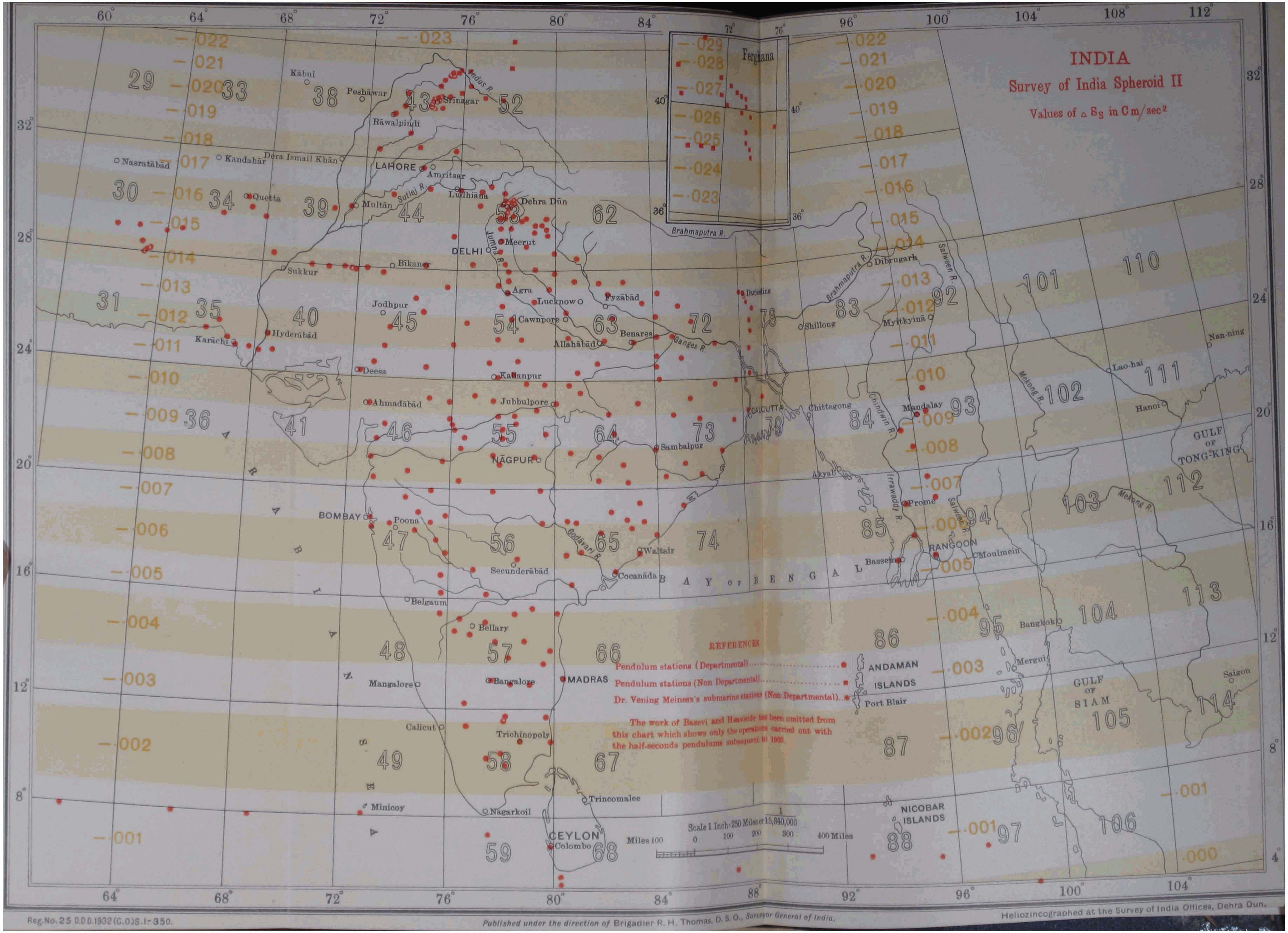
The work of Basevi and Heaviside has been omitted from this chart which shows only the operations carried out with the half-seconds pendulums subsequent to 1903.

Reg.No 2 40.D.D.1932(C.O.)S.1-350.

Published under the direction of Brigadier R. H. Thomas, D.S.O., *Surveyor General of India.*

1932

Heliozincographed at the Survey of India Offices, Dehra Dun.



INDIA

Survey of India Spheroid II

Values of ΔS_S in Cm/sec²

REFERENCES

Pendulum stations (Departmental) .... ●

Pendulum stations (Non Departmental) .... ■

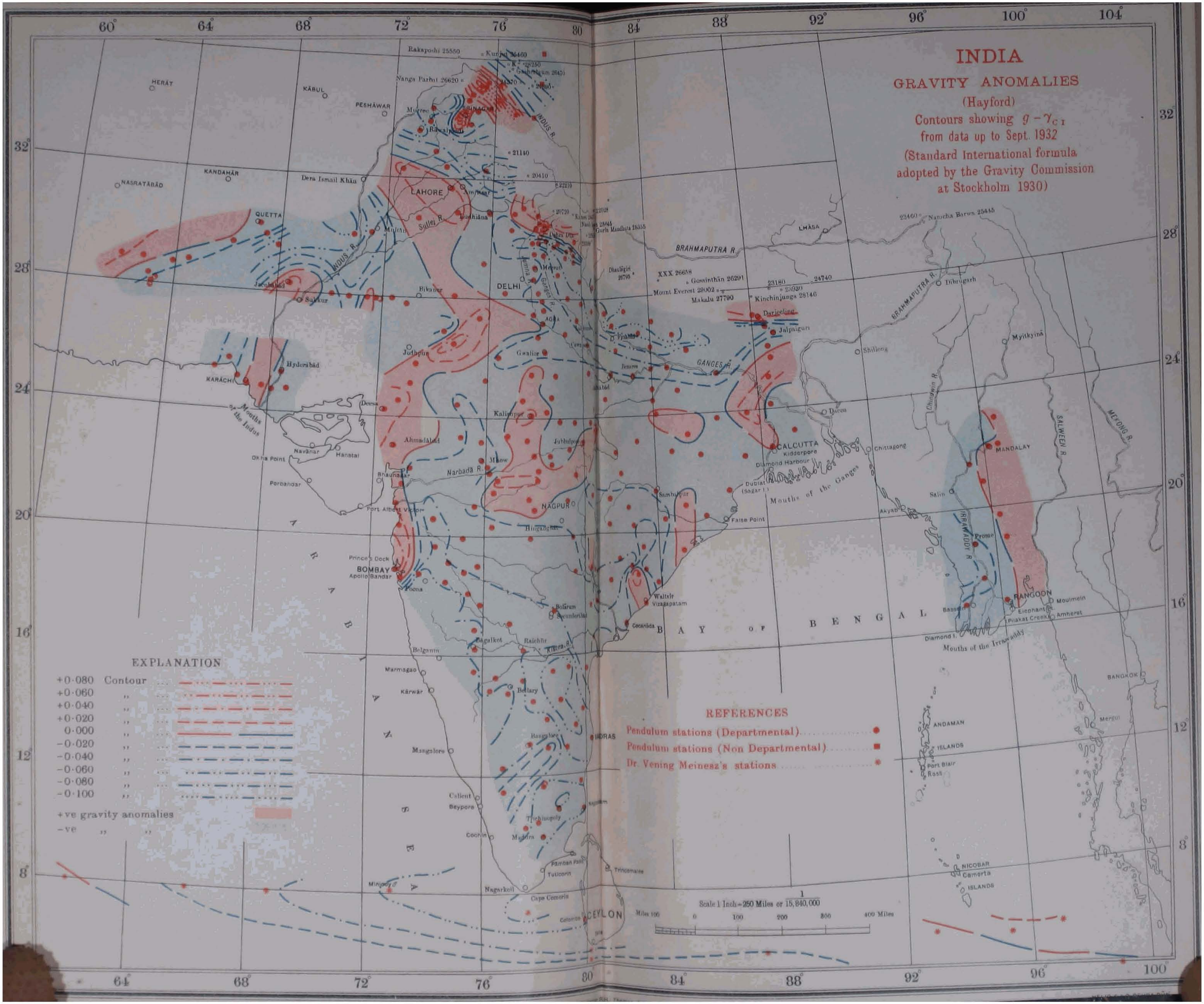
Dr. Vening Meinesz's submarine stations (Non Departmental).. ✱

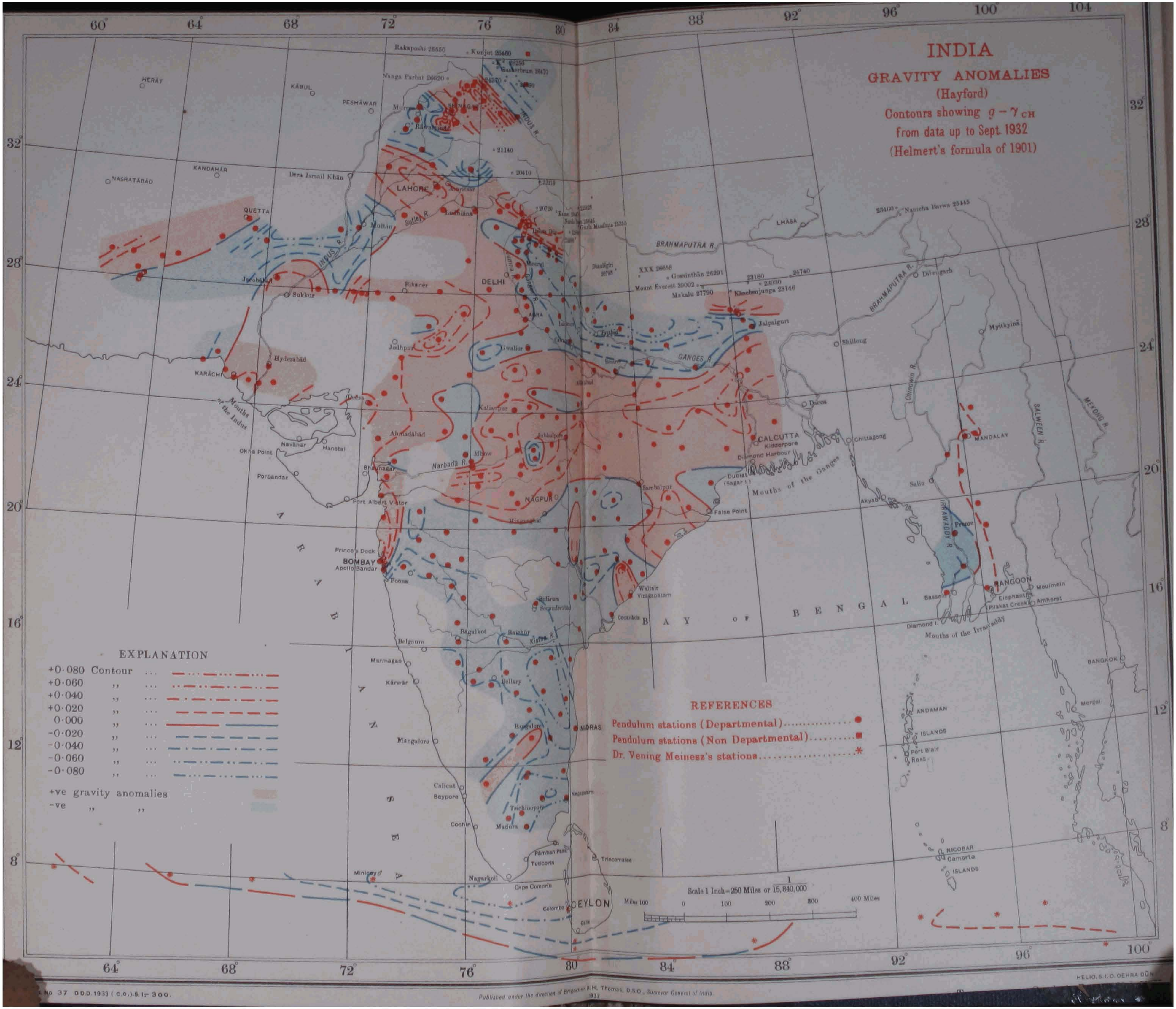
The work of Basevi and Heaviside has been omitted from this chart which shows only the operations carried out with the half-seconds pendulums subsequent to 1903.

Reg. No. 25 D.D.D. 1932 (C.O.) S.I.-350.

Published under the direction of Brigadier R. H. Thomas, D.S.O., Surveyor General of India.

Heliozincographed at the Survey of India Offices, Dehra Dun.





INDIA

GRAVITY ANOMALIES

(Hayford)

Contours showing $g - \gamma_{CH}$
from data up to Sept. 1932
(Helmert's formula of 1901)

EXPLANATION

+0·080	Contour	...
+0·060	,,	...
+0·040	,,	...
+0·020	,,	...
0·000	,,	...
−0·020	,,	...
−0·040	,,	...
−0·060	,,	...
−0·080	,,	...

+ve gravity anomalies
-ve ,, ,,

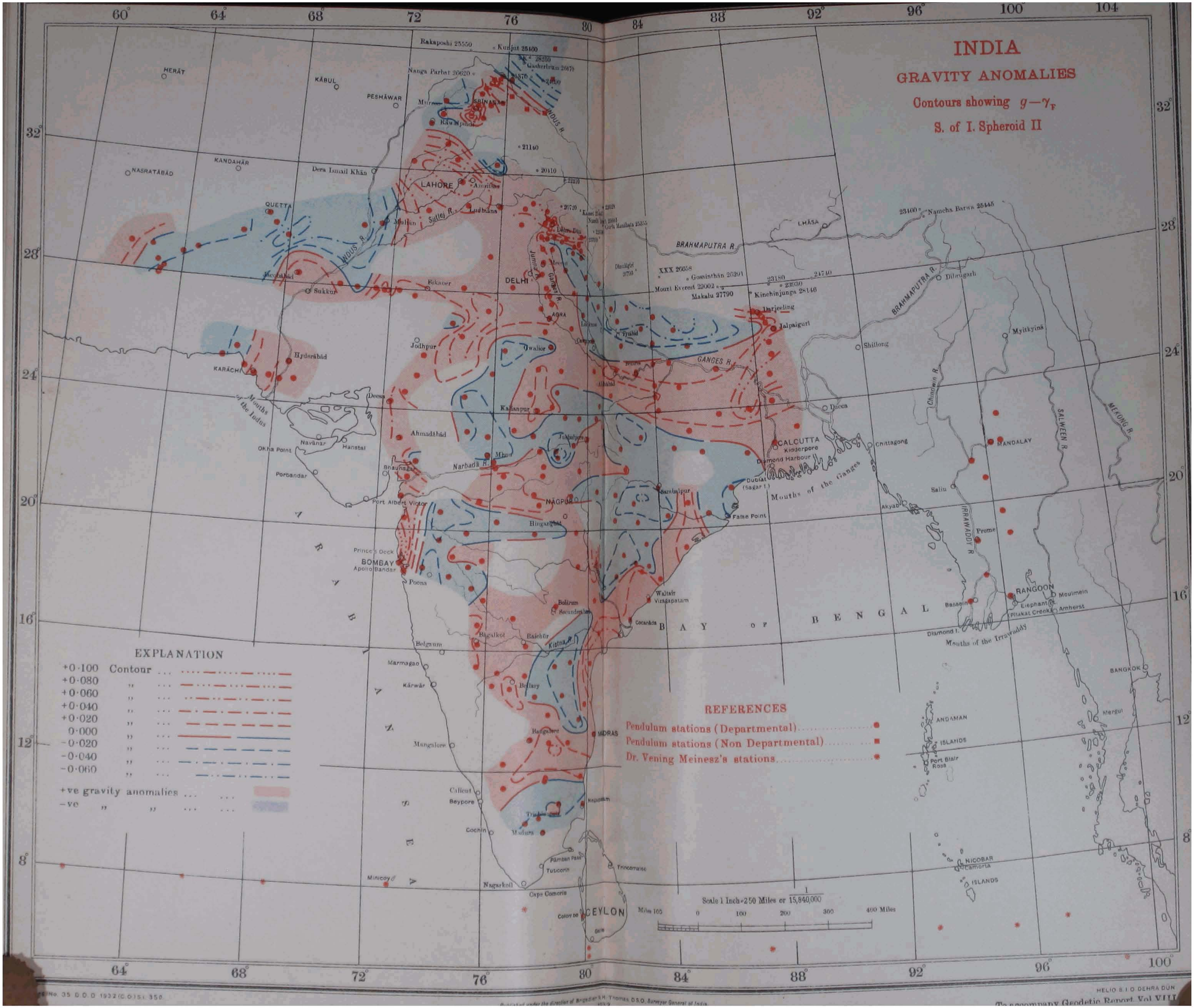
REFERENCES

Pendulum stations (Departmental) .... ●
Pendulum stations (Non Departmental) .... ■
Dr. Vening Meinesz's stations .... *

No 37 D.O.D. 1933 (C.O.)-S.1-300.

Published under the direction of Brigadier R.H. Thomas, D.S.O., Surveyor General of India. 1933

HELIO. S.I.O. DEHRA DŪN



No. 35 D.D.D 1932 (C.O.) S. 350

Published under the direction of Brigadier R.H. Thomas, D.S.O., Surveyor General of India. 1932

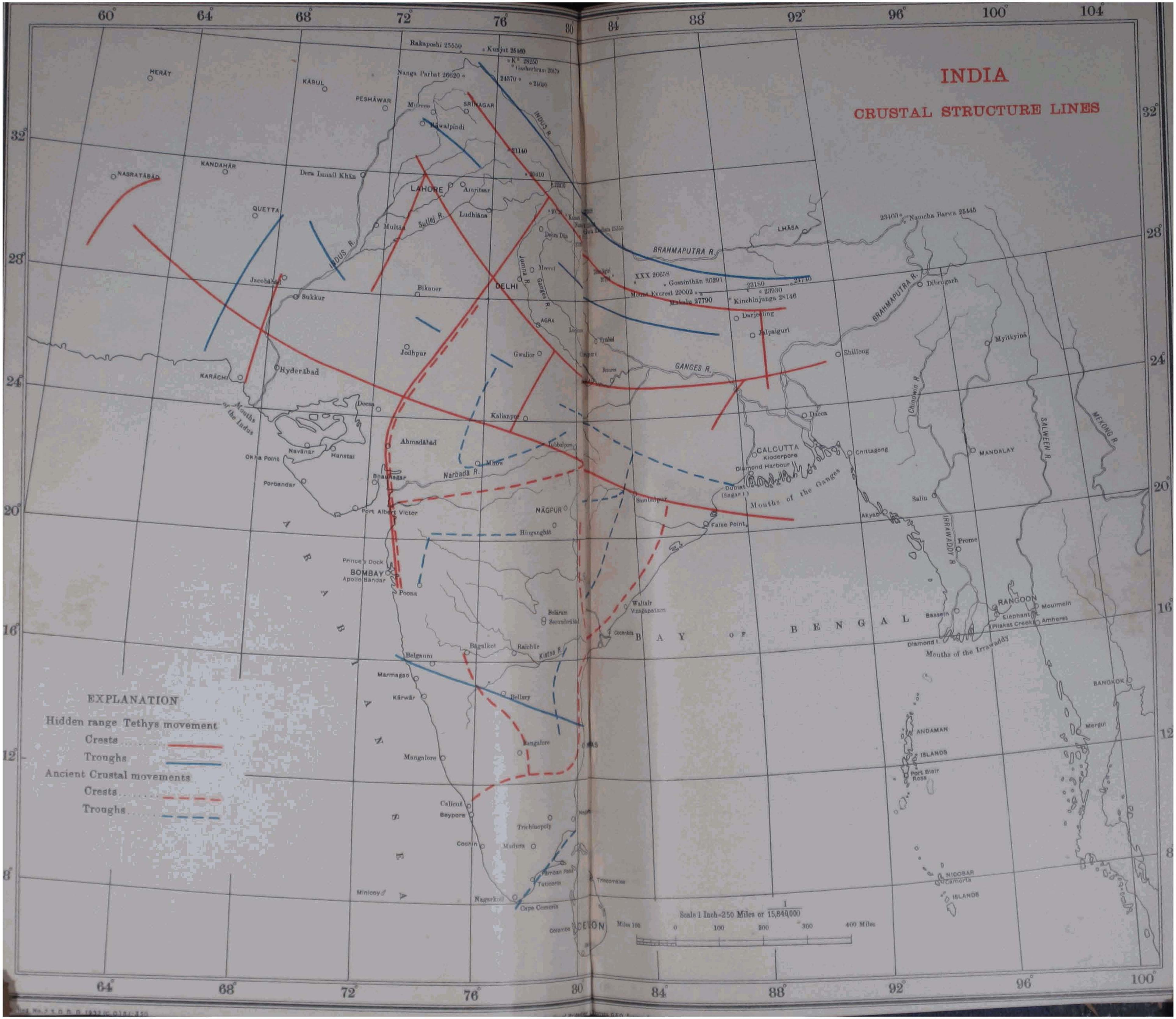
HELIO S.I.O. DEHRA DUN

To accompany Geodetic Report Vol VIII

No. 22. D. D. D. 1932 (C.O.) S. 1—305

Published under the direction of Brigadier R. H. Thomas, D.S.O., Surveyor General of India,

HELIO. S.I.O. DEHRA DŪN


INDIA
CRUSTAL STRUCTURE LINES
EXPLANATION
Hidden range Tethys movement
Crests
Troughs
Ancient Crustal movements
Crests
Troughs
Scale 1 Inch=250 Miles or 1/15,840,000
Miles 100
0
100
200
300
400 Miles
60°
64°
68°
72°
76°
80°
84°
88°
92°
96°
100°
104°
32°
28°
24°
20°
16°
12°
8°
HERĀT
KĀBUL
PESHĀWAR
KANDAHĀR
NASRATĀBĀD
QUETTA
Dera Ismail Khān
Jacobābād
Sukkur
KARĀCHI
Hyderābād
Mouths of the Indus
Rakaposhi 25550
Kunjut 25460
K² 28250
Gasherbrum 26470
Nanga Parbat 26620
24370
24690
Murree
SRINAGAR
Rawalpindi
INDUS R.
21140
20410
LAHORE
Amritsar
Multān
Sutlej R.
Ludhiāna
Dehra Dūn
Meerut
DELHI
Bikaner
Jumna R.
Ganges R.
AGRA
Jodhpur
Gwalior
Deesa
Kalianpur
Ahmadābād
Nāvānar
Hanstal
Okha Point
Porbandar
Bhaunagar
Mhow
Narbadā R.
Jubbulpore
Port Albert Victor
NĀGPUR
Hinganghāt
Prince's Dock
BOMBAY
Apollo Bandar
Poona
Bolārum
Secunderābād
Waltair
Vizagapatam
Cocanāda
Bāgalkot
Raichūr
Kistna R.
Belgaum
Marmagao
Kārwār
Bellary
Bangalore
MADRAS
Mangalore
Calicut
Beypore
Trichinopoly
Cochin
Madura
Pamban Pass
Tuticorin
Trincomalee
Minicoy
Nagarkoil
Cape Comorin
Colombo
CEYLON
A R A B I A N S E A
B A Y O F B E N G A L
LHĀSA
BRAHMAPUTRA R.
XXX 26658
Gosainthān 26291
Mount Everest 29002
Makalu 27790
Kinchinjunga 28146
23180
23930
24740
Darjeeling
Jalpaiguri
Benares
GANGES R.
Shillong
Dacca
CALCUTTA
Kidderpore
Diamond Harbour
Dublat (Sagar I.)
Mouths of the Ganges
Sambalpur
False Point
Chittagong
23460
Namcha Barwa 25445
Dibrugarh
Myitkyina
Chindwin R.
MANDALAY
SALWEEN R.
MEKONG R.
Akyab
Salin
IRRAWADDY R.
Prome
Bassein
RANGOON
Elephant Pt.
Pilakat Creek
Moulmein
Amherst
Diamond I.
Mouths of the Irrawaddy
BANGKOK
ANDAMAN ISLANDS
Port Blair
Ross
Mergui
NICOBAR ISLANDS
Camorta

INDIA
COMPENSATED GEOID

On Survey of India Spheroid II

$a = 6,378,541$ m. $\epsilon = 1/292{\cdot}4$

Deflections at origin 1″·98 S. & 2″·81 W.

Contours at 5-foot intervals.

Elevated geoid red, depressed geoid blue.

Reg. No. 34 D.D.D. 1932 (C.O.I.S.) 360.

Published under the direction of Brigadier [illegible] Thomas, D.S.O., Surveyor General of India.

HELIO. S.I.O. DEHRA DŪN.

To accompany Geodetic Report Vol. XXX

TABLE 1. *Times of vibration at Dehra Dūn, season 1931-32.*

Mercer Chronometer No. 12831.

Date		CA	AB	Mean
	1931			
		s	s	s
October	19	0·507 9514		
,,	20	9484		
,,	,, ...	9501		
,,	21	9511		
,,	,, ...		0·507 9509	
,,	22		9511	
	Mean ...	0·507 9503	0·507 9510	0·507 9507

Date		CA	AB	Mean
	1932			
		s	s	s
May	8	0·507 9490		
,,	9	9492		
,,	,, ...	9496		
,,	10		0·507 9506	
,,	11		9498	
,,	,, ...		9515	
	Mean ...	0·507 9493	0·507 9506	0·507 9500

Adopted mean times of vibration

	s	s	s
General Mean ...	0·507 9498	0·507 9508	0·507 9503

TABLE 2. *Differences between individual and mean pendulums, season 1931-32.* (The unit is 10^{-7} sec.).

Name of station	CA	*v*	AB	*v*
Dehra Dūn (October 1931) ...	+ 2	− 2	− 2	+ 2
Talegaon	+ 9	+ 5	− 9	− 5
Ahmednagar	+ 5	+ 1	− 5	− 1
Jāmkhed ...	+ 2	− 2	− 2	+ 2
Bhir	+ 5	+ 1	− 4	0
Sangamner ...	+ 5	+ 1	− 5	− 1
Satāna	+ 6	+ 2	− 6	− 2
Daulatābād	+ 4	0	− 4	0
Chikhli	+ 2	− 2	− 2	+ 2
Pusad	+ 8	+ 4	− 8	− 4
Nāgpur	− 1	− 5	+ 1	+ 5
Kānker ...	+ 6	+ 2	− 7	− 3
Jagdalpur ...	+ 4	0	− 4	0
Bijāpur (Bastar) ..	+ 2	− 2	− 1	+ 3
Bhopālpatnam	+ 5	+ 1	− 6	− 2
Bhadrāchalam	− 5	− 9	+ 5	+ 9
Sukma	+ 6	+ 1	− 5	− 1
Jeypore	+ 1	− 3	− 2	+ 2
Pottangi	+ 3	− 1	− 3	+ 1
Singpur	+ 1	− 3	− 1	+ 3
Tukla	+ 2	− 2	− 1	+ 3
Jonk	+ 2	− 2	− 2	+ 2
Sambalpur .. .	0	− 4	0	+ 4
Angul .	+ 3	− 1	− 3	+ 1
Phulbāni	+ 9	+ 5	− 9	− 5
Chaibāsa	+ 10	+ 6	− 10	− 6
Midnapore	+ 3	− 1	− 3	+ 1
Barrackpore	− 16	− 20	+ 17	+ 21
Jessore	+ 8	+ 4	− 9	− 5
Sūri	+ 2	− 2	− 1	+ 3
Dhānbād	+ 7	+ 3	− 7	− 3
Kolebira	+ 6	+ 2	− 6	− 2
Ambikāpur	+ 7	+ 3	− 7	− 3
Mangawān	+ 6	+ 2	− 5	− 1
Bānda	+ 2	− 2	− 2	+ 2
Shāhpur (Cawnpore) ...	+ 3	− 1	− 3	+ 1
Budaun	+ 2	− 2	− 2	+ 2
Haldwāni	+ 1	− 3	− 1	+ 3
Bhowāli	+ 5	+ 1	− 4	0
Rānikhet	+ 4	0	− 5	− 1
Darshani	+ 13	+ 9	− 12	− 8
Kumaria	− 1	− 5	+ 2	+ 6
Rāmnagar	+ 10	+ 6	− 10	− 6
Morādābād	− 6	− 10	+ 7	+ 11
Bijnor	+ 3	− 1	− 2	+ 2
Kotdwāra	+ 10	+ 6	− 10	− 6
Lansdowne	+ 6	+ 2	− 6	− 2
Dehra Dūn (May 1932) ...	+ 7	+ 3	− 6	− 2
Mean ...	+ 4		− 4	

TABLE 3. *Mean times of vibration and deduced values of g, season 1931-32.*

Name of Station		CA	AB	Mean
Talegaon	*s*	0·508 1328	0·508 1346	0·508 1337
	g	978·358	978·354	978·356
Ahmednagar	*s*	0·508 1241	0·508 1251	0·508 1246
	g	978·391	978·391	978·391
Jāmkhed	*s*	0·508 1273	0·508 1277	0·508 1275
	g	978·379	978·381	978·380
Bhīr	*s*	0·508 1187	0·508 1196	0·508 1192
	g	978·412	978·412	978·412
Sangamner	*s*	0·508 1115	0·508 1125	0·508 1120
	g	978·440	978·439	978·440
Satāna	*s*	0·508 1001	0·508 1013	0·508 1007
	g	978·484	978·483	978·484
Daulatābād	*s*	0·508 1074	0·508 1082	0·508 1078
	g	978·456	978·456	978·456
Chikhli	*s*	0·508 1039	0·508 1043	0·508 1041
	g	978·469	978·471	978·470
Pusad	*s*	0·508 0912	0·508 0928	0·508 0920
	g	978·518	978·516	978·517
Nāgpur	*s*	0·508 0676	0·508 0674	0·508 0675
	g	978·609	978·614	978·611
Kānker	*s*	0·508 0898	0·508 0911	0·508 0904
	g	978·524	978·522	978·523
Jagdalpur	*s*	0·508 1168	0·508 1176	0·508 1172
	g	978·419	978·420	978·420
Bijāpur (Bastar)	*s*	0·508 1075	0·508 1078	0·508 1077
	g	978·455	978·458	978·457
Bhopālpatnam	*s*	0·508 0821	0·508 0832	0·508 0826
	g	978·553	978·553	978·553
Bhadrāchalam	*s*	0·508 1042	0·508 1032	0·508 1037
	g	978·468	978·475	978·472
Sukma	*s*	0·508 1104	0·508 1115	0·508 1110
	g	978·444	978·444	978·444
Jeypore	*s*	0·508 1245	0·508 1248	0·508 1246
	g	978·390	978·392	978·391
Pottangi	*s*	0·508 1290	0·508 1296	0·508 1293
	g	978·372	978·374	978·373
Singpur	*s*	0·508 0924	0·508 0926	0·508 0925
	g	978·513	978·516	978·515
Tukla	*s*	0·508 0769	0·508 0772	0·508 0771
	g	978·573	978·576	978·575
Jonk	*s*	0·508 0777	0·508 0781	0·508 0779
	g	978·570	978·572	978·571
Sambalpur	*s*	0·508 0530	0·508 0530	0·508 0530
	g	978·665	978·669	978·667
Angul	*s*	0·508 0497	0·508 0523	0·508 0510
	g	978·678	978·672	978·675
Phulbāni	*s*	0·508 0870	0·508 0887	0·508 0879
	g	978·534	978·531	978·533

Continued.

TABLE 3. *Mean times of vibration and deduced values of g, season 1931-32—(contd.).*

Name of Station		CA	AB	Mean
Chaibāsa	*s*	0·508 0386	0·508 0406	0·508 0396
	g	978·721	978·717	978·719
Midnapore	*s*	0·508 0258	0·508 0263	0·508 0261
	g	978·770	978·772	978 771
Barrackpore	*s*	0·508 0176	0·508 0143	0·508 0160
	g	978·802	978·818	978·810
Jessore	*s*	0·578 0111	0·508 0128	0·508 0119
	g	978·827	978·824	978·826
Sūri	*s*	0·507 9935	0·507 9938	0·507 9937
	g	978·895	978·897	908·896
Dhānbād	*s*	0·508 0140	0·508 0154	0·508 0147
	g	978·816	978·814	978·815
Kolebira	*s*	0·508 0558	0·508 0570	0·508 0564
	g	978·655	978·654	978·654
Ambikāpur	*s*	0·508 0550	0·508 0564	0·508 0557
	g	978·657	978·656	978·657
Mangawān	*s*	0·508 0075	0·508 0086	0·508 0081
	g	978·841	978·840	978·841
Bānda	*s*	0.507 9811	0·507 9815	0·507 9813
	g	978·943	908·942	978·943
Shāhpur (Cawnpore)	*s*	0·507 9734	0·507 9740	0·507 9737
	g	978·972	978·974	978·973
Budaun	*s*	0·507 9508	0·507 9512	0·507 9510
	g	979·059	979·061	979·060
Haldwāni	*s*	0·507 9657	0·507 9659	0·507 9658
	g	979·002	979·005	979·003
Bhowāli	*s*	0·508 0234	0·508 0243	0·508 0239
	g	978·779	978·780	978·779
Rānikhet	*s*	0·508 0266	0·508 0275	0.508 0270
	g	978·767	978·767	978·767
Darshani	*s*	0·507 9965	0·507 9990	0·507 9978
	g	978·883	978·877	978·880
Kumaria	*s*	0·507 9630	0·507 9627	0·507 9629
	g	979·012	979·017	979·015
Rāmnagar	*s*	0·507 9580	0·507 9600	0·507 9590
	g	979 032	979·028	979·030
Morādābād	*s*	0·507 9471	0·507 9458	0·507 9465
	g	979·073	979·082	979·078
Bijnor	*s*	0·507 9323	0·507 9328	0·507 9326
	g	979·130	979·132	979·131
Kotdwāra	*s*	0·507 9456	0·507 9477	0·507 9467
	g	979·079	979·075	979·077
Lansdowne	*s*	0·508 0088	0·508 0100	0·508 0094
	g	978·836	979·835	978·835

TABLE 4. *Modern gravity observations in India.*
(Additions in field season 1931-32).

No.	Sheet No.	Station	Date	Height	Latitude N.	Longitude E.	g	$g-\gamma_A$	$g-\gamma_B$	$g-\gamma_C$
				feet	° ′ ″	° ′ ″	*cm/sec²*	*cm/sec²*	*cm/sec²*	*cm/sec²*
228	47 F	Talegaon ...	21 11 31	2060	18 44 01	73 40 44	978·356	−·014	−·083	−·048
229	47 I	Ahmednagar ...	24 11 31	2164	19 04 49	74 45 54	978·391	+·013	−·060	−·011
230	47 N	Jāmkhed ...	27 11 31	1906	18 44 17	75 18 20	978·380	−·004	−·068	−·021
231	47 N	Bhīr ...	30 11 31	1753	18 59 38	75 41 56	978·412	−·001	−·060	−·013
232	47 I	Sangamner ...	4 12 31	1803	19 33 36	74 12 29	978·440	·000	−·061	−·020
233	46 L	Satāna ...	8 12 31	1854	20 35 53	74 12 13	978·484	−·011	−·073	−·035
234	47 M	Daulatābād ...	11 12 31	1887	19 55 06	75 12 46	978·456	+·004	−·059	−·014
235	55 D	Chikhli ...	14 12 31	2076	20 20 24	76 15 55	978·470	+·010	−·060	−·015
236	56 E	Pusad ...	17 12 31	1109	19 54 46	77 33 45	978·517	−·008	−·045	−·009
237	55 O	Nāgpur ...	21 12 31	1019	21 09 18	79 03 42	978·611	+·004	−·030	+·005
238	64 H	Kānker ...	27 12 31	1325	20 14 43	81 30 30	978·523	−·001	−·046	−·008
239	65 I	Jagdalpur ...	30 12 31	1821	19 05 32	82 01 44	978·420	+·009	−·052	−·017
240	65 B	Bijāpur (Bastar)	3 1 32	1150	18 47 35	80 48 57	978·457	−·001	−·039	−·013
241	65 B	Bhopālpatnam	6 1 32	460	18 51 42	80 22 50	978·553	+·027	+·012	+·033
242	65 C	Bhadrāchalam	14 1 32	173	17 40 14	80 53 23	978·472	−·018	−·024	−·025
243	65 F	Sukma ...	18 1 32	630	18 24 12	81 39 47	978·444	−·037	−·060	−·040
244	65 J	Jeypore ...	22 1 32	1959	18 51 50	82 34 30	978·391	+·005	−·060	−·023
245	65 J	Pottangi ...	25 1 32	3059	18 33 56	82 58 03	978·373	+·107	+·008	+·038
246	65 M	Singpur ...	31 1 32	1156	19 29 54	83 18 40	978·515	+·018	−·020	+·016
247	64 L	Tukla ...	5 2 32	682	20 14 57	82 51 08	978·575	−·009	−·032	−·002
248	64 L	Jonk ...	8 2 32	1015	20 55 24	82 30 41	978·571	−·022	−·056	−·024
249	64 O	Sambalpur ...	12 2 32	564	21 27 42	83 59 00	978·667	−·001	−·020	+·004
250	73 H	Angul ...	16 2 32	425	20 49 57	85 06 11	978·675	+·032	+·018	+·032
251	73 D	Phulbāni ...	19 2 32	1540	20 26 11	84 13 48	978·533	+·018	−·033	−·007
252	73 F	Chaibāsa ...	24 2 32	769	22 32 41	85 48 35	978·719	+·002	−·024	+·006
253	73 N	Midnapore ...	28 2 32	129	22 25 16	87 19 35	978·771	+·002	−·002	+·006
254	79 B	Barrackpore ...	2 3 32	21	22 45 59	88 20 50	978·810	+·009	+·006	+·016
255	79 E	Jessore ...	7 3 32	22	23 09 41	89 12 33	978·826	−·001	−·002	+·008
256	73 M	Sūri ...	11 3 32	264	23 54 42	87 31 36	978·896	+·043	+·034	+·055
257	73 I	Dhānbād ...	14 3 32	761	23 48 08	86 25 40	978·815	+·015	−·011	+ 020
258	73 B	Kolebira ...	17 3 32	1880	22 42 04	84 41 52	978·654	+·031	−·032	+·014
259	64 M	Ambikāpur ...	21 3 32	1953	23 06 48	83 11 50	978·657	+·014	−·052	+·002
260	63 H	Mangawān ...	26 3 32	1038	24 38 43	81 33 53	978·841	+·010	−·025	+·015
261	63 C	Bānda ...	29 3 32	420	25 28 45	80 19 54	978·943	−·003	−·017	+·013
262	63 B	Shāhpur (Cawnpore) ...	1 4 32	412	26 27 50	80 15 29	978·973	−·043	−·057	−·023
263	53 P	Budaun ...	4 4 32	551	28 01 34	79 07 41	979·060	−·058	−·077	−·026
264	53 O	Haldwāni ...	6 4 32	1466	29 13 21	79 31 57	979·003	−·121	−·167	−·045
265	53 O	Bhowāli ...	9 4 32	5600	29 22 59	79 30 52	978·779	+·031	−·151	+·001
266	53 O	Rānikhet ...	11 4 32	5944	29 37 38	79 26 08	978·767	+·032	−·159	+·021
267	53 O	Darshani ...	14 4 32	3996	29 53 27	79 36 24	978·880	−·059	−·187	+·029
268	53 O	Kumaria ...	18 4 32	1866	29 32 14	79 09 43	979·015	−·095	−·151	−·008
269	53 O	Rāmnagar ...	20 4 32	1119	29 23 37	79 07 20	979·030	−·139	−·174	−·052
270	53 L	Morādābād ...	23 4 32	651	28 50 53	78 46 07	979·078	−·093	−·115	−·045
271	53 K	Bijnor ...	25 4 32	764	29 22 49	78 08 01	979·131	−·070	−·096	−·016
272	53 K	Kotdwāra ...	27 4 32	1261	29 44 39	78 31 16	979·077	−·106	−·145	−·024
273	53 K	Lansdowne ...	29 4 32	5558	29 50 30	78 41 00	978·835	+·047	−·134	+·031

Corrigenda. Supplement to Vol. VI.

Page lxii. Station No. 26, under Sheet No. *read* 34.O *for* 35.O

" lxiii. Station No. 67, under Sheet No. and Long. *read* 55.N and 79° 29′ *for* 55.F and 77° 29′ respectively.

" lxvi. Station No. 200, under latitude *read* 14° 27′ 52″ *for* 14° 17′ 52″.

NOTE. This table is the second addendum to the list of gravity stations given in the Supplement to Geodetic Report Vol. VI.

TABLE 5. *Values of $g-\gamma_F$.*

Station No.	Compensation to 22·7 miles	S. of I—II			Station No.	Compensation to 22·7 miles	S. of I—II		
		Hidden Range effect	$g-\gamma_C$	$g-\gamma_F$			Hidden Range effect	$g-\gamma_C$	$g-\gamma_F$
	cm/sec²	*cm/sec²*	*cm/sec²*	*cm/sec²*		*cm/sec²*	*cm/sec²*	*cm/sec²*	*cm/sec²*
228	+·020	−·019	−·034	−·023	251	+·014	+·028	+·005	−·025
229	+·021	−·011	+·001	+·003	252	+·008	+·030	+·020	−·006
230	+·018	−·013	−·010	−·003	253	+·001	+·030	+·020	+·001
231	+·017	−·010	−·001	+·004	254	·000	+·027	+·030	+ 015
232	+·028	−·006	−·008	−·018	255	·000	+·024	+·023	+·011
233	+·018	+·005	−·023	−·034	256	+·003	+·016	+·070	+·063
234	+·018	+·001	−·001	−·008	257	+·007	+·018	+·035	+·022
235	+·018	+·006	−·002	−·014	258	+·016	+·026	+·029	−·001
236	+·012	+·007	+·004	−·003	259	+·020	+·032	+·017	−·023
237	+·010	+·023	+·018	−·003	260	+·010	+·025	+·031	+·008
238	+·013	+·022	+·004	−·019	261	+·004	+·021	+·029	+·016
239	+·004	+·017	−·004	−·023	262	+·004	+·015	−·006	−·013
240	+·010	+·007	−·002	−·007	263	+·005	+·002	−·007	−·002
241	+·006	+·006	+·044	+·044	264	+·022	−·011	−·025	−·024
242	+·003	−·005	−·015	−·001	265	+·038	−·018	+·021	+·013
243	+·008	+·005	−·024	−·025	266	+·042	−·020	+·041	+·031
244	+·022	+·014	−·011	−·035	267	+·052	−·024	+·050	+·034
245	+·024	+·012	+·049	+·025	268	+·028	−·017	+·012	+·013
246	+·020	+·021	+·028	−·001	269	+·018	−·016	−·032	−·022
247	+·010	+·024	+·010	−·012	270	+·006	−·004	−·026	−·016
248	+·011	+·028	−·011	−·038	271	+·008	−·007	+·004	+·015
249	+·005	+·031	+·017	−·007	272	+·020	−·017	−·004	+·005
250	+·006	+·030	+·045	+·021	273	+·033	−·020	+·052	+·051

TABLE 6. *Values of $g-\gamma_{CI}$*

Station No.	$g-\gamma_{CI}$	Station No.	$g-\gamma_{CI}$	Station No.	$g-\gamma_{CI}$	Station No.	$g-\gamma_{CI}$	Station No.	$g-\gamma_{CI}$	Station No.	$g-\gamma_{CI}$
1	−·010	55	+·013	109	−·021	163	+·003	217	−·004	271	−·032
2	−·072	56	+·004	110	+·014	164	+·032	218	+·010	272	−·040
3	+·045	57	+·005	111	−·026	165	−·002	219	−·039	273	+·015
4	...	58	+·020	112	+·019	166	·000	220	−·039	**Stations of De Filippi Expedition**	
5	+ 037	59	−·006	113	∓·031	167	+·021	221	−·011		
6	−·012	60	−·013	114	+·030	168	−·032	222	−·014		
7	−·012	61	−·010	115	+·022	169	+·009	223	−·038		
8	+·022	62	+·012	116	−·003	170	−·023	224	+·027	**Wozul Hadur**	+·021
9	−·037	63	−·009	117	+·006	171	−·025	225	−·004		
10	−·014	64	−·005	118	+·003	172	+·002	226	−·008		
11	+·004	65	−·021	119	−·030	173	−·024	227	−·026	**Depsang**	−·079
12	−·056	66	−·021	120	−·046	174	−·020	228	−·066	**Skärdu**	·000
13	+·015	67	+·018	121	−·071	175	−·031	229	− 029	**Yārkand**	−·071
14	−·007	68	+ 013	122	−·055	176	−·026	230	−·039		
15	+·031	69	−·020	123	−·071	177	−·063	231	−·031		
16	+·020	70	−·008	124	−·084	178	−·061	232	−·038	**Dr. V. Meinesz's sea station**	
17	+·002	71	−·045	125	−·079	179	−·045	233	−·053		
18	−·014	72	−·002	126	−·102	180	−·076	234	−·032	15	+·002
19	+·024	73	−·022	127	−·108	181	−·059	235	−·031	16	−·024
20	+·022	74	−·036	128	−·105	182	−·077	236	−·027	17	−·026
21	−·088	75	−·013	129	−·116	183	−·077	237	−·013	18	−·061
22	+·003	76	+·008	130	−·016	184	+·050	238	−·026	19	−·097
23	−·080	77	+·008	131	−·038	185	−·057	239	−·035	20	−·063
24	−·047	78	+·005	132	−·063	186	−·059	240	−·032	21	−·053
25	+·022	79	+·010	133	−·040	187	−·048	241	+·015	22	−·020
26	−·075	80	·000	134	−·053	188	−·033	242	−·044	23	−·020
27	−·019	81	+·014	135	−·045	189	−·046	243	−·058	24	−·014
28	−·009	82	−·002	136	−·005	190	−·031	244	−·041	25	+·018
29	−·033	83	−·015	137	+·002	191	−·044	245	+·020	26	+·017
30	−·060	84	+·008	138	+·028	192	−·044	246	−·002	27	−·007
31	−·045	85	+·013	139	+·017	193	−·037	247	−·020		
32	−·023	86	−·014	140	+·020	194	−·059	248	−·042		
33	−·008	87	−·042	141	+·075	195	− 086	249	−·014		
34	−·011	88	−·045	142	+·047	196	−·095	250	+·015		
35	−·013	89	−·008	143	+ 080	197	−·061	251	−·025		
36	−·012	90	−·022	144	+·002	198	−·046	252	−·012		
37	+·003	91	− 031	145	+·006	199	−·091	253	−·012		
38	+·017	92	−·059	146	−·003	200	−·089	254	−·001		
39	+·010	93	−·074	147	−·007	201	−·059	255	−·009		
40	−·044	94	−·087	148	+·019	202	−·053	256	+·038		
41	−·042	95	−·019	149	+·035	203	−·041	257	+·003		
42	−·010	96	+·009	150	+·002	204	−·023	258	−·003		
43	−·067	97	+·005	151	−·040	205	−·020	259	−·015		
44	−·052	98	+·002	152	−·036	206	−·001	260	−·002		
45	−·007	99	+·022	153	−·010	207	−·036	261	−·004		
46	−·051	100	−·003	154	+·008	208	+·007	262	−·040		
47	−·028	101	−·024	155	−·007	209	−·009	263	−·042		
48	−·032	102	+·012	156	−·003	210	−·009	264	−·061		
49	−·037	103	−·022	157	−·009	211	−·005	265	−·015		
50	−·013	104	·000	158	−·007	212	−·009	266	+·005		
51	+·029	105	−·002	159	−·025	213	+·009	267	+·013		
52	+·012	106	−·006	160	−·024	214	−·033	268	−·024		
53	+·002	107	−·025	161	−·023	215	+·045	269	−·068		
54	+·008	108	−·035	162	−·010	216	−·021	270	−·061		

CHAPTER V

TRIANGULATION

BY CAPTAIN G. BOMFORD, R. E.

1. Summary. The season's programme consisted of primary triangulation in Baluchistān with one detachment, and comprised the reconnaissance and observation of the Dālbandin Meridional series, which runs roughly along the meridian 65° East, and connects the Kalāt and Makrān Longitudinal series.

Astronomical observations were made for latitude at 7 stations, and for azimuth at 5. These provided additional data regarding the form of the geoid in Baluchistān, of which the outline has now been determined.

2. Strength of the party. The field detachment was organized as follows:

Observing ...	Captain G. Bomford, R.E.
	1 Recorder.
	16 Khalāsis.
	9 Escort.
Station-building ...	Mr. Khushal Khan, Sub-Asstt. Supdt.
	15 Khalāsis.
	9 Escort.
13 Heliotrope squads ...	3 Khalāsis each.

3. Transport and supplies. 55 camels were engaged as permanent transport, and a variable number of donkeys in addition (up to 15), for moving light camps over difficult ground. On the average it was found possible to get donkeys up to about 1,000 feet below the stations, although at some stations the building material, camp and water had to be carried up 2,000 feet or more. It was sometimes possible to engage 5 to 10 local men to help in this work.

Although the country has a bad reputation for shortage of water, sufficient good water was nearly always found at the heads of *nālas* in the hills on which stations were built. When marching from station to station it was found convenient to carry enough water for one night, but it was never necessary to camp for two successive nights out of reach of water. In winter the local camels only require water every second day, and can go without it for a third, if necessary.

Indian Triangulation. (*See* Records of the Survey of India Vol. IX, p. 137).

For 42 Series entering the Simultaneous Grinding (shown in italics below) Mean Square M = ± 1·04
For Series up to No. 107 ... ... Mean Square M = ± 1·52

No.	Name of Series	Seasons	± *m*	± M
1	South Pārasnāth Mer. ...	1831-39	3·308	3·26
2	Budhon Meridional ...	1833-43	2·242	2·46
3	*Amūa Meridional* ...	1834-38	1·647	1·88
4	*Rangīr Meridional* ...	1834-64	1·643	1·79
5	*Calcutta Longitudinal* ...	1834-69	0·369	0·32
6	*Great Arc Meridional, Section 24°-30°* * ...	1835-66	0·708	0·71
7	*Bombay Longitudinal* ...	1837-63	0·844	0·74
8	*Great Arc Meridional, Section 18°-24°* ...	1838-41	0·567	0·59
9	*Great Arc Meridional, Section 8°-18°* ...	1840-74	0·390	0·36
10	*Singi Meridional* ...	1842-62	1·187	1·14
11	*South Konkan Coast* ...	1842-67	2·176	1·93
12	*Karāra Meridional* ...	1843-45	1·507	1·81
13	*North Malūncha Mer.* ...	1844-46	1·266	1·42
14	*Chendwār Meridional* ...	1844-69	0·841	1·06
15	*Gora Meridional* ...	1845-47	0·973	1·21
16	*Calcutta Meridional* ...	1845-48	1·173	1·99
17	South Malūncha Mer. ...	1845-53	1·606	1·97
18	*Khānpisura Meridional* ...	1845-62	1·227	1·07
19	*Gurwāni Meridional* ...	1846-47	1·165	1·55
20	*North-East Lon.* ...	1846-55	0·446	0·65
21	*Hurīlāong Meridional* ...	1848-52	1·502	1·92
22	*North-West Himālaya* ...	1848-53	0·641	0·55
23	*Gurhāgarh Meridional* ...	1848-62	0·914	1·21
24	*East Coast* ...	1848-63	0·608	0·70
25	*Karāchi Longitudinal* ...	1849-53	0·558	0·60
26	*Abu Meridional* ...	1851-52	0·617	0·68
27	*North Pārasnāth Mer.* ...	1851-52	0·895	1·25
28	*Kāthiāwār Meridional* ...	1852-56	0·990	1·11
29	*Gujarāt Longitudinal* ...	1852-62	0·859	1·12
30	Kāthiāwār Lon. ...	1853	1·481	1·34
31	Sābarmati ...	1853-54	1·348	2·84
32	*Great Indus* ...	1853-61	0·359	0·43
33	*Rāhon Meridional* ...	1853-63	0·327	0·37
34	*Assam Longitudinal* ...	1854-60	0·579	0·71
35	*Cutch Coast* ...	1855-58	0·986	1·27
36	Kashmīr Principal ...	1855-60	0·884	0·86
37	*Jogī-Tila Meridional* ...	1855-63	0·481	0·59
38	Sambalpur Lon. ...	1856-57	0·806	0·87
39	(Cutch) Coast Line ...	1856-60	0·975	1·47
40	Kāthiāwār Meridional No. 1 ...	1858-59	0·930	1·51
41	Kāthiāwār Meridional No. 2 ...	1859-60	1·247	1·75
42	Kāthiāwār Meridional No. 3 ...	1859-60	0·969	1·48
43	*Bīdar Longitudinal* ...	1859-72	0·311	0·30
44	*Eastern Frontier or Shillong Meridional* ...	1860-64	0·409	0·49
45	*Sutlej* ...	1861-63	0·346	0·53
46	*Madras Mer. and Coast* ...	1861-68	0·426	0·40
47	Kāthiāwār Meridional No. 4 ...	1863-64	1·154	1·73
48	*East Calcutta Lon.* ...	1863 69	0·379	0·57
49	*Mangalore Meridional* ...	1863-73	0·440	0·45
50	Kumaun and Garhwāl ...	1864-65	1·742	1·50
51	Nāsik ...	1864-65	2·033	3·12
52	Burma Coast (*See* 106) ...	1864-82	0·380	0·39
53	*Jubbulpore Meridional* ...	1865-67	0·340	0·31
54	*Madras Longitudinal* ...	1865-80	0·384	0·37
55	Assam Valley Triangulation ...	1867-78	1·690	2·65
56	*Brahmaputra Mer.* ...	1868-74	0·564	0·70
57	Coimbatore No. 1 ...	1869-71	1·547	2·07
58	*Bilāspur Meridional* ...	1869-73	0·302	0·33
59	Cuddapah ...	1871-72	0·826	0·96
60	Hyderābād ...	1871-72	1·405	1·56
61	Malabar Coast ...	1871,74,80	1·532	1·82
62	Jodhpur Meridional ...	1873-76	0·291	0·32
63	*South East Coast* ...	1875-79	0·522	0·65
64	Eastern Sind Mer. ...	1876-81	0·244	0·30
65	Siam Branch Triangulation ...	1878-81	3·711	4·34
66	Mandalay Meridional ...	1889-95	0·418	0·35
67	Mong Hsat * ...	1891-93	3·054	3·01
68	Manipur Longitudinal ...	1894-99	0·453	0·36
69	Makrān Longitudinal ...	1895-97	0·285	0·26
70	Mandalay Lon ...	1899-1909	1·696	1·96
71	Manipur Mer. ...	1899-1902 1915-1916	0·750	0·81
72	Great Salween (*See* 105)	1900-11	0·404	0·32
73	Kidarkanta ...	1902-03	1·323	1·62
74	Kalāt Longitudinal ...	1904-08	0·365	0·25
75	Baluchistān Triangulation ...	1908-09	1·348	1·08
76	North Baluchistān ...	1908-10	0·221	0·17
77	Gilgit ...	1909-11	0·443	0·37
78	Khāsi Hills ...	1909-11	2·038	3·01
80	Upper Irrawaddy ...	1909-11	0·596	0·49
81	Jaintia Hills ...	1910-11	0·986	1·86
82	Bhīr ...	1911-12	0·794	0·94
83	Rānchi ...	1911-12	1·840	2·34
84	Villupuram ...	1911-12	1·184	1·78
85	Sambalpur Meridional ...	1911-14	0·250	0·21
86	Indo-Russian Connection	1912-13	2·790	3·92
87	Khandwa ...	1912-13	0·999	1·27
88	Ashta ...	1913-15	1·048	1·33
89	Buldāna ...	1913-14	0·304	0·43
90	Naldrug ...	1913-14	1·465	1·85
91	Nāga Hills ...	1913-14	0·913	0·96
92	Middle Godāvari ...	1914-15	0·913	1·08
93	Kohīma ...	1914-15	1·094	1·39
94	Cāchār ...	1914-15	1·077	1·65
95	Bombay Island ...	1911-14	...	...
96	Madura ...	1916-17	1·148	1·53
97	Bāgalkot ...	1916-17	0·701	0·83
99	Rangoon ...	1925-27	1·246	1·25
100	Kurram ...	1927-28	2·096	2·26
101	Peshāwar ...	1927-28	1·267	0·96
102	North Wazīristān ...	1927-28	1·895	2·47
103	Chittagong ...	1928-30	0·453	0·45
104	Mong Hsat ...	1929-31	0·441	0·38
105	Great Salween ...	1929-31	0·682	0·58
106	Burma Coast ...	1930-31	0·205	0·19
107	Dālbandin ...	1931-32	...	...

Mer. = Meridional   Lon. = Longitudinal.

* Replaced by 104.

INDIA
TRIANGULATION SERIES AND AZIMUTH STATIONS
Corrected to Sept. 1932.

REFERENCES

Series of Triangulation	⟫
Additions since 1931	⟫
Number of Series (Vide table opposite)	23
Base Line	▬
Astronomical Azimuths	▲

Triangulation series and bases of Ceylon, Siam, Indo-China, Malaya & Russia are shown in red.

In some cases where stations lie very close to each other some are omitted.

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

Reg No 31 D.D.D.1932(C.O.)S.I-325

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Heliozincographed at the Survey of India Offices, Dehra Dūn.

No supplies, other than water, firewood and grazing, can be obtained in the area visited, except at Dālbandin, Khārān Kalāt, Panjgūr and Jau, and about one month's supplies were generally carried.

In the matter of supplies and transport, the party was fortunate in receiving the most willing assistance from the Nawāb of Khārān.

4. Narrative of season's work. The station-building detachment left Dālbandin on 1st November to build a station on the Rās Koh. The observing detachment left on 3rd November to assist the reconnaissance by building Malik Surinda H.S., where they were surprised to find a station already built, probably by the party engaged on the Kalāt Longitudinal series in 1908. It was consequently only necessary to post the helio squad. The highest point on the Rās Koh (9,872), on the other hand, proved to be too narrow for the building of a station, and no other near point could be found from which all necessary stations were visible. The difficulty was eventually overcome by the observing party building a new station, Shehin, on a hill 5 miles west of the Rās Koh, and revisiting Kisanen Chappar H.S. from which observations to an unsuitable point on the Rās Koh had already been made. The work then proceeded according to plan without unforeseen difficulties occurring.

Trouble had been expected from the great length of some of the rays employed, especially from that between Malik Surinda H.S. and Choto-i-jik H.S., which is 80 miles long, across the Khārān desert, but in the clear air of Baluchistān they caused no difficulty, a 12-inch heliotrope often appearing uncomfortably bright in the telescope. This ray is notable as the longest side in the figures of the Indian geodetic triangulation.

Examination of existing maps had suggested that the stations at Razak and Choto-i-jik might not be intervisible, and this proved to be the case. Any other siting of these stations would have greatly reduced the strength of the triangles crossing the Khārān desert, and the difficulty was overcome by the expedient described in para 5.

Mr. Khushal Khan had completed the building of his 10 stations by 28th December, and he posted the last heliotrope on Buzgalaband H.S. on 5th January, within a few hours of the time appointed in the programme drawn up before work started. Observations were completed at Churchuri H.S. on 14th January.

The party was favoured with very good weather, only four days being wasted by reason of bad visibility, although thin layers of high cloud frequently caused much anxiety and annoyance by dimming the heliotropes. There were occasional showers of rain, but only two really wet days. Some discomfort was caused by a very cold north wind during parts of December. The health of the party was excellent.

5. Ray Razak–Choto-i-jik. As mentioned above, these two stations were not intervisible, while it was most undesirable to adopt a shorter side as a base for the large triangles to the north. The following expedient was therefore adopted. A third station, Puchinak H.S., almost in a straight line with the other two, was built on the intervening ridge, and observations were made between it and Choto-i-jik and Razak (see Chart XIV). The ratio of the sides Choto-i-jik–Puchinak and Puchinak–Razak was also determined by observations between Puchinak and Zangilak H.S. The small angles Puchinak—Choto-i-jik—Razak and Puchinak–Razak–Choto-i-jik can be determined from the above data, with the result that the angles of the triangle Salāmbek—Choto-i-jik—Razak and of the quadrilateral Choto-i-jik—Gandān can be calculated, and these figures can be computed as if the stations at Choto-i-jik and Razak had been intervisible. The indirect determination of the angles involves a little loss of strength but much less than would have resulted from any possible re-arrangement of the lay-out.

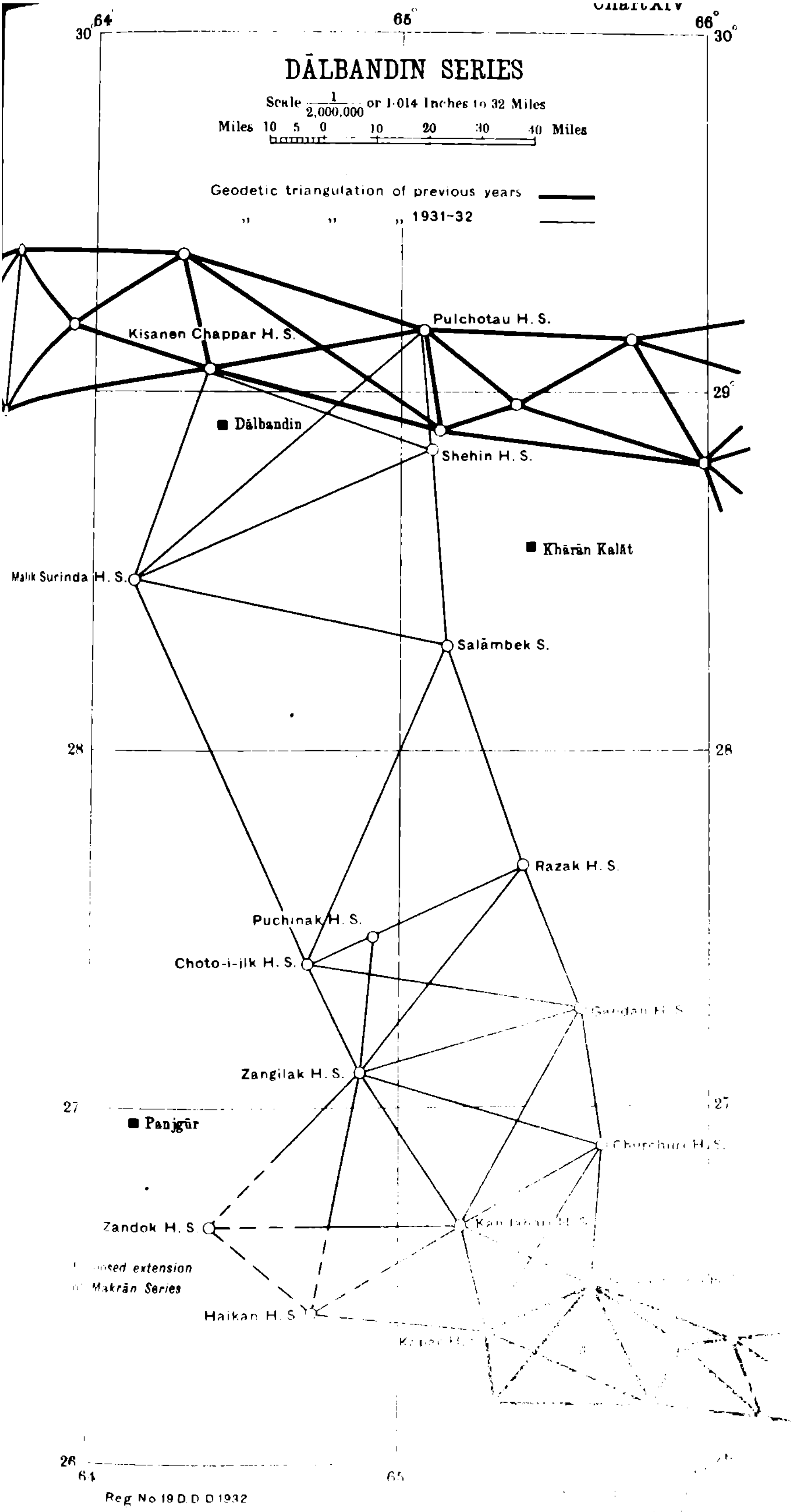
6. Wild theodolite. The instrument employed was Wild Precision Theodolite No. 59. This instrument had just been to the makers for reconditioning, and was in perfect order. It worked excellently, and caused no anxiety or trouble. Details of the out-turn of work, and accuracy, are given in Table 1. The average triangular error of 0″·71 is well up to the usual primary standard, while the out-turn, of 9,650 square miles in 9 weeks of observation, exceeds what could be hoped for from a 12-inch theodolite even under the favourable conditions enjoyed in Baluchistān.

The programme of observation was 3 measures face-right or 3 face-left on each of 20 zeros, intersections of each station being made in pairs and repeated if the difference exceeded 2 seconds. With this programme a station with 5 or 6 rays can be completed in a single full day if the heliotropes are showing steadily, but at all except one station observations were spread over parts of at least two days in order to lessen the risk of serious lateral refraction. This was the more important since no observations were made at night, the Argand lamps being dispensed with on account of transport difficulties.

7. Connections with other triangulation. Table 2 shows the closing error of the circuit formed by the Kalāt, Great Indus, Makrān and Dālbandin series. The first three of these have already received some provisional adjustment, so that the figures given are not those which would have arisen if the circuit had been computed by itself. The zero closing error in log side is, of course, attributable only to chance: if the previous adjustments had been ignored, it would have been 0·0000057, a reasonable value. The

CHART XIV

DĀLBANDIN SERIES



Reg No 19 D.D. D 1932

To accompany Geodetic Report

closing error in position, about 13 feet, represents 1 : 250,000 of the length of the circuit, which is satisfactory.

In accordance with the usual custom, in order to provide self-consistent values for immediate topographical use, the closing errors have been distributed through the Dālbandin series, without disturbing the series which have already been adjusted. The small size of the closing errors has made it possible to distribute them by a less elaborate method than that usually employed, without doing undue violence to the observed angles.

Several stations of the series are identical with stations and intersected points of old topographical or exploratory triangulation. The errors of the latter are shown in Table 3. The points concerned are all sharp and no considerable part of the discrepancies can be attributed to lack of identity. Although the errors are large, as judged by modern standards, the majority are barely plottable at the scale of ¼ inch = 1 mile, and they show that the old triangulators maintained a standard well suited to the work which they had in hand.

8. Astronomical observations. With a view to adding to our knowledge of the form of geoid in Baluchistān, astronomical latitudes were observed at the 7 stations forming the eastern flank of the series, and azimuth was also observed at 5 of them. The results are given in Table 4.

The latitude programme consisted of observations to Polaris and three circum-meridian stars, two south and one north. Three face-right and three face-left measures were made of each. The computations show a surprising fact, namely that the latitude derived from the south member of a north and south pair was invariably greater than that derived from the north member, the average being $4''\cdot 2$. See Table 5, columns 2 and 3. Such discrepancies are generally attributed to error in the assumed refraction, but such a large difference is hardly possible on this account. Moreover, if this was the cause, the difference should be greater in low altitude pairs than in high, which is not the case. It is thought the discrepancy may be due to the fact that no diagonal eye-piece or reflecting prism was used, and that under these circumstances the observer tends to look into the eye-piece somewhat from one side. If parallax is present this discrepancy will then result, but it is hard to see why it should be of the same sign at 7 different stations. The accordance of the means of high and low altitude pairs suggests that fairly accurate cancellation has taken place when north and south pairs are meaned, and from the last column of the table $0''\cdot 6$ is deduced as the probable error of the mean at each station. This is sufficient for the object in view.

The azimuth programme consisted of observations to Polaris, one face right and one face left on each of 10 zeros. The accordance of zero means gives an average probable error of $0''\cdot 45$ for the astronomical azimuth, which after multiplying by $\cot \lambda$ is equivalent to $0''\cdot 85$ in the deduced deviation of the vertical.

The Wild theodolite has sometimes been criticized on the grounds that it is not well adapted to astronomical work. This criticism is thought to be entirely unfounded. A programme of 4 latitude stars, 6 time stars, and azimuth on 10 zeros was completed on the average in 3 hours, in very cold weather.

9. The Geoid in Baluchistan. Chart XV shows all the stations in Baluchistān at which the deviation of the vertical has yet been observed, and the anomalies found. The data are hardly sufficient for an accurate determination of the form of the geoid, but they fall roughly into two lines along which fairly accurate integration is possible. Starting at Vijnot T. S. with the compensated geoid 25 feet above the International spheroid (see Geodetic Report Vol. VII, Chart X, fig. II), integration via Jacobābād, Quetta, Dālbandin, Jau, and Karāchi, to Khori T. S. gives the height of the compensated geoid there as 44 feet. This does not compare very well with the value of 30 feet shown in Geodetic Report Vol. V, Chart XII, but the western edge of the geoid as shown in the chart cannot be considered to be well determined. Geodetic Report Vol. VII, Chart X has shown that the 20 and 25-foot contours required to be bent considerably to the north between longitudes 68° and 70° so that it is probable that the 30 and 35-foot contours require some similar modification. In this case Khori T. S. would about fall on the 35-foot contour, leaving an error of 9 feet to be distributed round the circuit. This has been done. A second line of deflections extends westwards from Dālbandin, and with the height at Dālbandin determined, integration along it presents no difficulty.

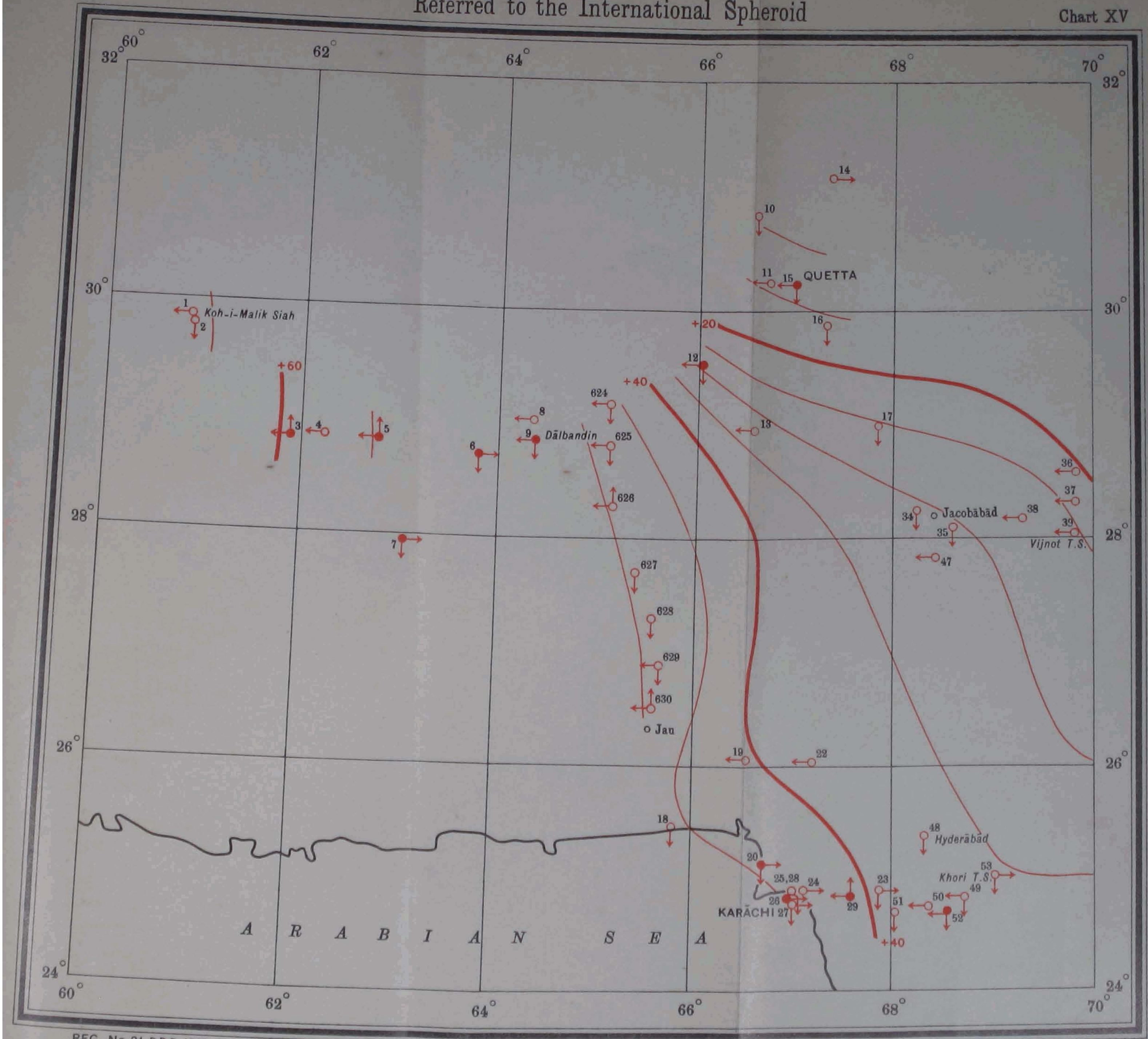
East of longitude 65° the prime vertical deflections depend either on longitude stations, or on azimuth stations which are included in a well-closed circuit of triangulation. See Table 2: the closing error in azimuth is only $1''\cdot 3$. The small difference of $0''\cdot 9$ between the prime vertical anomaly at Dālbandin longitude station and the nearby azimuth station at Kisanen Chappar (No. 8) also suggests that there has been no serious accumulation of azimuth error, and that these prime vertical deflections are accurate. West of Dālbandin, on the other hand, the prime vertical deflections depend on the azimuth of an unclosed series, and the $5''\cdot 7$ difference between Warechah longitude station (No. 3) and Tuzgi azimuth station (No. 4) suggests that the azimuths may be in error by 2 seconds or so, although the two stations are too far apart for this to be more than a suggestion, and the quality of the triangulation is such that an error of $2''$ in azimuth is not to be expected.

It may. therefore, be concluded that east of longitude 65° the broad outlines of the compensated geoid are correctly shown along the circuit of integration, but that the further geoidal rise to the west although probably correct, is not so certainly established.

COMPENSATED GEOID

Referred to the International Spheroid

Chart XV



REG. No 21 D.D.D. 1932

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REFERENCES

Latitude Station	1○↑
Azimuth Station	2○→
Longitude Station	3●→

Scale 1/5,000,000 or 1·014 Inches to 80 Miles

Miles 50 25 0 50 100 Miles

Contours at 5-foot intervals.

Note:— The numbers refer to the

The great separation between the compensated geoid and the International spheroid is notable. Even in the well-established part it is 50 *per cent* greater than has been found anywhere else in India, and the gravity anomalies (see Chart VII), do not suggest that this geoidal rise is due to local excess of mass. Presumably the rise is simply evidence of the general bad fit between the International spheroid and the geoid in this part of Asia. If the Survey of India No. II[*] spheroid is adopted as a figure of reference, the geoidal anomalies are considerably reduced, although they remain large: the rise from east to west between longitudes 70° and 61° is reduced by 20 feet, and that from north to south between Quetta and the coast is reduced by 15 feet. A consideration of the geoidal form and of the intensity of gravity in Kashmīr (see Geodetic Report Vol. VII, Chapter IV, Section I) has suggested that the International spheroid does not fit the compensated geoid well, and the present extension into Baluchistān confirms this opinion: it even seems to go further and to call for a spheroid with a larger major axis and consequently greater flattening than the Survey of India No. II spheroid.

TABLE 1. *Primary Triangulation 1931-32*

Dālbandin Meridional Series

Season	1931-32
Number of new stations built	12†
Number of stations observed at	14
Length of triangulation in miles	190
Area in square miles	9,650‡
Mean length of sides in miles	·44
Number of triangles observed	20
Average triangular error	0″·71
Maximum triangular error	1″·89
Value of *m*	0″·472
Value of M §	0 ·32
Value of *p* ‖	4 ·55 feet
Value of P ‖	3 ·09 feet
Order of merit	8 (*eq*)
Instruments used	Wild No. 59

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[*] $a = 6{,}378{,}541$ metres, $b = 6{,}356{,}073$ metres, $1/\epsilon = 292 \cdot 4$

† Includes two stations of extension into Makrān, built and observed to, but not visited

‡ Includes 3/5 of area of partially observed figure of extension into Makrān.

§ See Professional Paper No. 16, page 91

‖ See Geodetic Report Vol III, page 27.

TABLE 2. *Closing errors of Dālbandin Meridional Series.*

	(a) In terms of Kalāt Long. and Dālbandin Mer.	(b) In terms of Makrān Long	(a) − (b)
Latitude of Buzgalaband H.S. ...	26° 30′ 04″·23	26° 30′ 04″·33	−0″·10
Longitude of Buzgalaband H.S. ...	65 37 28 ·01	65 37 27 ·93	+0 ·08
Height of Buzgalaband H S. (feet)	3369	3361	+8
Log side Buzgalaband-Kapar ..	5·0826793	5·0826793	0·0000000
Azimuth of Kapar at Buzgalaband	68° 28′ 04″·7	68° 28′ 03″·4	+1″·3

TABLE 3. *Connections with old Topographical triangulation.*
Latitudes and Longitudes in seconds, heights in feet.

Station		Discrepancy. New *minus* Old			
		Khārān △n. 1883-84	Tate 1889-90	Talbot 1889-90	Kitchen 1889-92
Malik Surinda ...	Lat.		+ 2·44*	− 1·98	
	Long.		− 1·86	+ 7·42	
	Height		−62		
Razak ...	Lat.	−0·70*		+ 3·35	+ 1·17
	Long.	+1·02		+ 4·79	+ 0·09
	Height			+ 7	− 3
Choto-i-jik ...	Lat.			+ 2·99	+ 1·90
	Long.			+ 6·94	+ 0·08
	Height			+11	− 9
Gandān ...	Lat.				+ 0·96
	Long.				− 0·38
	Height				+ 1
Zangilak ...	Lat.			+ 3·86	+ 1·70
	Long.			+ 7·16	− 0·40
	Height			+26	+19
Churchuri ...	Lat.			+ 5·3*	+ 1·0*
	Long.			+ 6·1	− 1·4
	Height			+23	− 6
Kandahari ..	Lat.				+ 1·5*
	Long.				− 1·2
	Height				+ 28

* Intersected point of old triangulation.

DEFLECTION STATIONS

Second Addendum to Table 1 of "Supplement" to G. R. Vol. VI.

TABLE 4

Serial No.	Sheet No.	Observed at	Height in feet	International Spheroid Deflections		Calculated Deflections Hayford System		Calculated Deflections Uncompensated Topography to 2564 miles	
				Meridian	P. V.	Meridian	P V.	Meridian	P. V.
				″	″	″	″	″	″
624	34 G	Pulchotau H.S.	4253	+ 2·1	− 0·4	+1·6	−1·3		
625	34 H	Shehin H.S.	8699	+ 6·7	+ 3·9	+2 *	−3 *		
626	34 H	Salāmbek H S	2178	− 1·5	+ 2·4	−0·7	−2·0		
627	35 E	Razak H.S.	6775	+ 8·1		+3 *			
628	35 E	Gandān H.S.	7522	− 5·1		−7 *			
629	35 F	Churchuri H S.	6815	− 7·5	+13·2	−8 *	+5 *		
630	35 F	Buzgalaband H.S.	3361	− 8·0	+18·8	−8 *	+2 *		

* These figures may be in error by two or three seconds on account of the absence of adequate maps.

DEFLECTIONS 1931-32.

EVEREST'S SPHEROID						Serial No.
Latitude	Longitude	Azimuth	Name of station observed for Azimuth	Deflections		
				Meridian	P.V.	
° ′ ″	° ′ ″	° ′ ″		″	″	
A 29 11 04·6 G 29 11 06·9	G 65 05 47·8	A 79 27 35·3 G 79 27 31·4	Kisanen Chappar H·S	− 2·3	+ 7·4	624
A 28 49 52·1 G 28 49 49·6	G 65 06 08·9	A 110 16 55·3 G 110 16 49·1	Kisanen Chappar H S.	+ 2·5	+ 11·3	625
A 28 17 35·9 G 28 17 41·4	G 65 09 02·4	A 175 28 14·4 G 175 28 11·7	Shehin H.S.	− 5·5	+ 9·7	626
A 27 42 17·5 G 27 42 13·2	G 65 23 58·5			+ 4·3		627
A 27 16 34·1 G 27 16 42·9	G 65 35 07·3			− 8·8		628
A 26 53 32·7 G 26 53 43·6	G 65 39 04·7	A 106 17 37·4 G 106 17 26·3	Zangilak H.S.	−10·9	+ 20·3	629
A 26 29 53·0 G 26 30 04·3	G 65 37 28·0	A 183 29 54·8 G 183 29 41·9	Churchuri H.S.	−11·3	+ 25·9	630

Corrigendum. Supplement to Vol. VI, *page* xv.

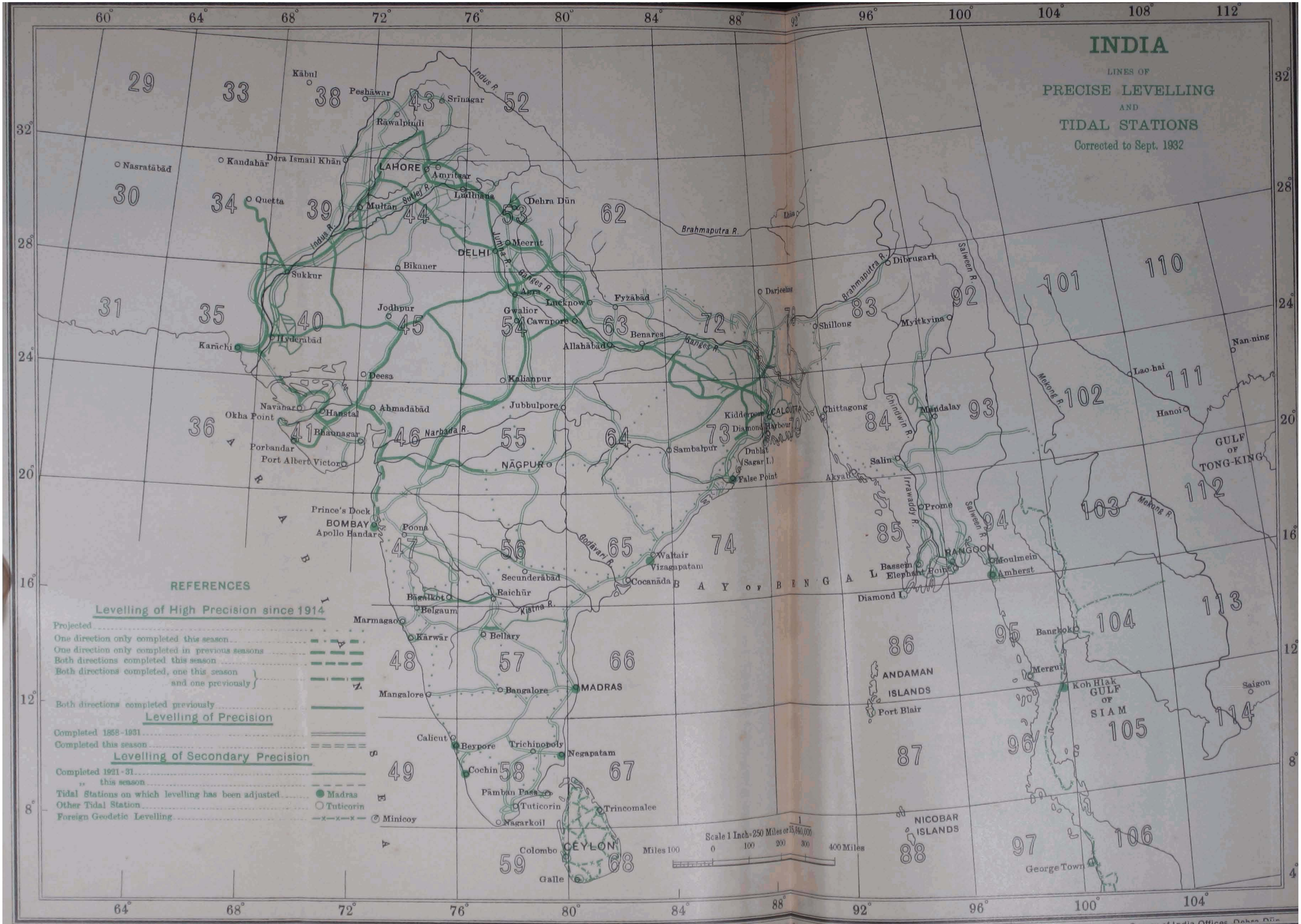
Station No. 2, under Longitude, *for* 60° 5′ 10″·90 *read* 60° 55′ 10″·90.

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

TABLE 5. *Astronomical Latitude.*

Station	Latitude by south star *minus* Latitude by north star		Latitude by mean of low altitude pair *minus* Latitude by high altitude pair
	Low altitude pair	High altitude pair	
Col. 1	Col. 2	Col. 3	Col. 4
Pulchotau ...	+1″·5	+0″·6	−1″·3
Shehin	+2·8	+8·2	+0·3
Salāmbek ...	+2·7	+4·4	−1·3
Razak	+6·1	+4·0	+1·0
Gandān	+4·0	+4·2	+2·7
Churchuri ...	+6·7	+9·0	+0·9
Buzgalaband ...	+3·3	+1·3	−3·0
	Mean + 3·9	Mean + 4·5	R. M. S. =1″·90

Probable error of mean at one station = ½ × 0·67 × R.M.S.
= 0″ 63.



INDIA

LINES OF

PRECISE LEVELLING

AND

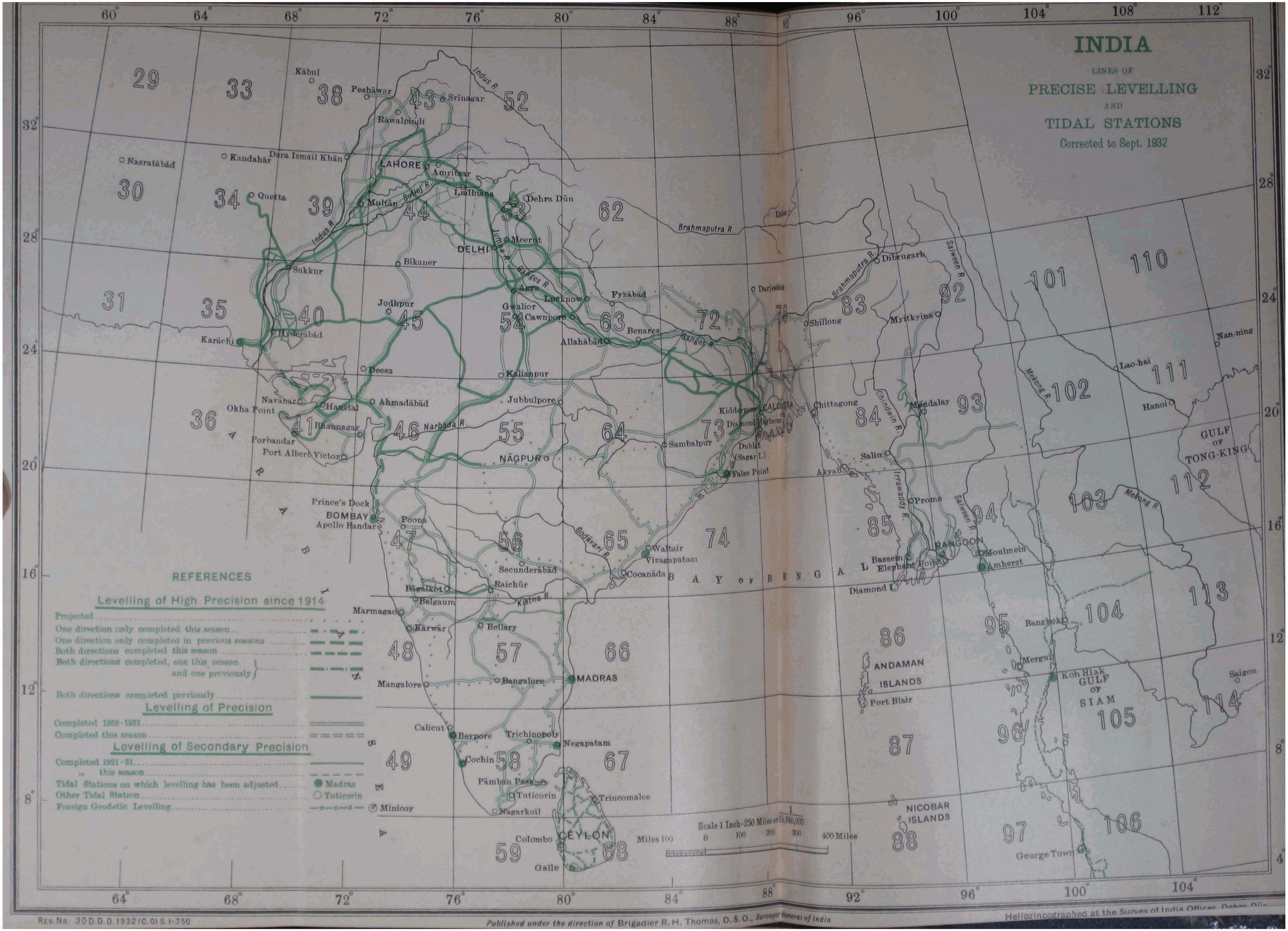
TIDAL STATIONS

Corrected to Sept. 1932

Reg. No. 30 D.D.D. 1932 (C.O.) S.I-350

Published under the direction of Brigadier R. H. Thomas, D. S. O., *Surveyor General of India*

Heliozincographed at the Survey of India Offices, Dehra Dūn



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CHAPTER VI

LEVELLING

BY LIEUT. I.H.R. WILSON, R.E.

1. Organization. Three detachments were formed and employed throughout the season as follows: two on secondary levelling, and one on tertiary levelling.

No. 17 Party (Levelling) was amalgamated with No. 15 Party (Triangulation) from 1st March 1932 under the designation of No. 15 Party (Triangulation and Levelling).

Secondary levelling was carried out for the Bhakra Dam Project (Punjab Irrigation), for the Bihār and Orissa P. W. D. (Irrigation Department), and for the Lloyd Barrage Project. Tertiary revision levelling was carried out in Bahāwalpur State, where discrepancies between the Survey and the P. W. D. had come to light. This amounted to the revision of some 445 east-and-west lines and *partalling* in 67 sheets.

2. Summary of out-turn. The total out-turn of levelling was as follows:

Secondary levelling 778 miles (870 gross)*.

Tertiary levelling 4,560 miles.

3. Work of detachments. *No. 1 detachment* under Mr. P. B. Roy, with Computer I. M. Saklani as second leveller, and Mr. A. P. Datta (U. S. S. Probationer under training), was employed on the following secondary levelling in connection with the Bihār and Orissa flood area drainage scheme:

(*a*) Chāribātia to Kendrāpāra, partly along Kendrāpāra canal, but the major part was across country via Rangini, Rājnagar, and Kiarbank, crossing *en route* the Dhāmra river which is about 1¼ miles wide, by both Target and Vertical Angle methods. Total mileage 89 miles (102 gross).

(*b*) Kiarbank to Puri, partly along unmetalled roads, and partly across country via Anantpur, Māchgaon and Konārak. Total mileage 89 miles (95 gross).

(*c*) Puri back to Puri, across country as far Jānkia and then along metalled roads via Khurda and Pipli. Total mileage 89 miles (94 gross).

---

* The first of these figures represent the direct distance levelled between terminal bench marks. The gross total includes additional check-levelling at ends and branch-lines to G. T. Stations etc.

No. 2 detachment under Mr. I. D. Suri, with Computer Hamid Ullah Khan as second leveller, and Mr. Gopalaiengar (U. S. S. Probationer under training), was employed on the following secondary levelling for the Bhakra Dam Project (Punjab Irrigation):

(*a*) Bhiwāni to Bahādurgarh partly along the railway line and partly along unmetalled and metalled roads via Dādri and Jhajjar. Total mileage 78 miles (80 gross).

(*b*) Hānsi to Bhatinda, partly along Hissār distributary of the western Jumna canal and partly along the railway line via Jīnd and Jakhal. Total mileage 136 miles (140 gross).

(*c*) Mānsa to Sohūwāla, partly along Musha Branch canal and partly along the camel track via Phaggu. Total mileage 41 miles (51 gross).

(*d*) Badopāl to Narwāna, partly along the metalled road and partly along Sirsa Branch canal via Sūnyāna. Total mileage 47 miles (67 gross).

(*e*) Narwāna to Rājpura, partly along the road and partly along Sirsa Branch canal via Kaithal and Patiāla. Total mileage 91 miles (112 gross).

(*f*) Dorāha to Patiāla, along Patiāla Branch canal (Feeder) and the Patiāla navigation channel via Bhūrthala and Rohti. Total mileage 42 miles (43 gross).

(*g*) Chandigarh to Dorāha, partly along metalled road and partly along the Sirhind canal via Rūpar. Total mileage 72 miles (82 gross).

No. 3 detachment under Mr. A. A. S. Matlub Ahmad, with 11 levellers and 1 camp assistant, were employed in revising some of the levelling carried out in Bahāwalpur State for the Sutlej Valley Project in seasons 1924–25–26, as discrepancies had been found between the 17 Party and the P. W. D. values. This involved the revision of 3,957 miles of single tertiary levelling along east-and-west lines and 603 miles of *partal* levelling on north-and-south lines. In order to complete the work before the end of financial year this detachment was reinforced by Mr. Mohd. Faizul Hasan and Computer Sibte Ali who joined on 23rd December 1931.

On the completion of this work, at the request of the Chief Engineer Lloyd Barrage, Mr. Mohd. Faizul Hasan, with Computer Sibte Ali as second leveller, was also employed on connecting the bench marks fixed at the ends of the barrage road bridge at Sukkur with line 101 (portion Jacobābād-Khānpur), the total length levelled being only 4 miles.

4. Probable errors. Probable errors of secondary levelling were computed from the formula: $p.e. = \pm \frac{1}{3}\sqrt{\frac{\Sigma\Delta^2}{L}}$, where Δ is the discordance between two levellers and L the total distance.

These are given below in foot and mile units :

Detachment	Line	Probable error
No. 1 Detachment	75 F Chāribātia–Kendrāpāra	±0·00377
,, ,,	75 G Kiarbank–Puri	±0·00313
,, ,,	39 B Puri–Puri	±0·00314
No. 2 Detachment	57 S Bhiwāni–Bahādurgarh	±0·00408
,, ,,	57 T Hānsi–Bhatinda	±0·00383
,, ,,	57 U Mānsa–Sohūwāla	±0·00330
,, ,,	57 V Badopāl–Narwāna	±0·00325
,, ,,	57 W Narwāna–Rājpura	±0·00359
,, ,,	61 K Chandigarh–Dorāha	±0·00272
,, ,,	57 X Dorāha–Patiāla	±0·00311
Sukkur Barrage Dett.	52 M S. B. M. at Sukkur–Barrage road bridge, Sukkur	±0·00386

5. Progress of the new level net. No high precision levelling was carried out during this field season, so the total figure given in Geodetic Report Vol. VII remains unchanged.

6. Bench marks. The following bench marks have been added to the list of Primary Protected bench marks published in Geodetic Report Vol. III, 1926-27.

Degree sheet	No. of bench mark	Degree sheet	No. of bench mark
40 C	505	53 L	326
43 H	90	54 D	47, 70
45 D	159, 166	54 K	184
45 G	178 *(77)* †	73 K	129
		73 M	269, 302, 328, 330, 326, 342
45 H	53, 67	73 N	18, 65, 83, 88, 122
45 J	125, 134	73 O	81, 97 *(26)*, † 100
45 O	21, 73 76, 93, 115, 124, 137		
45 P	19	79 B	909, 918, 951
53 G	351 *(196)* †	93 G	4
		93 H	56
53 H	124, 566	93 K	55
53 K	143, 235	93 O	21, 54

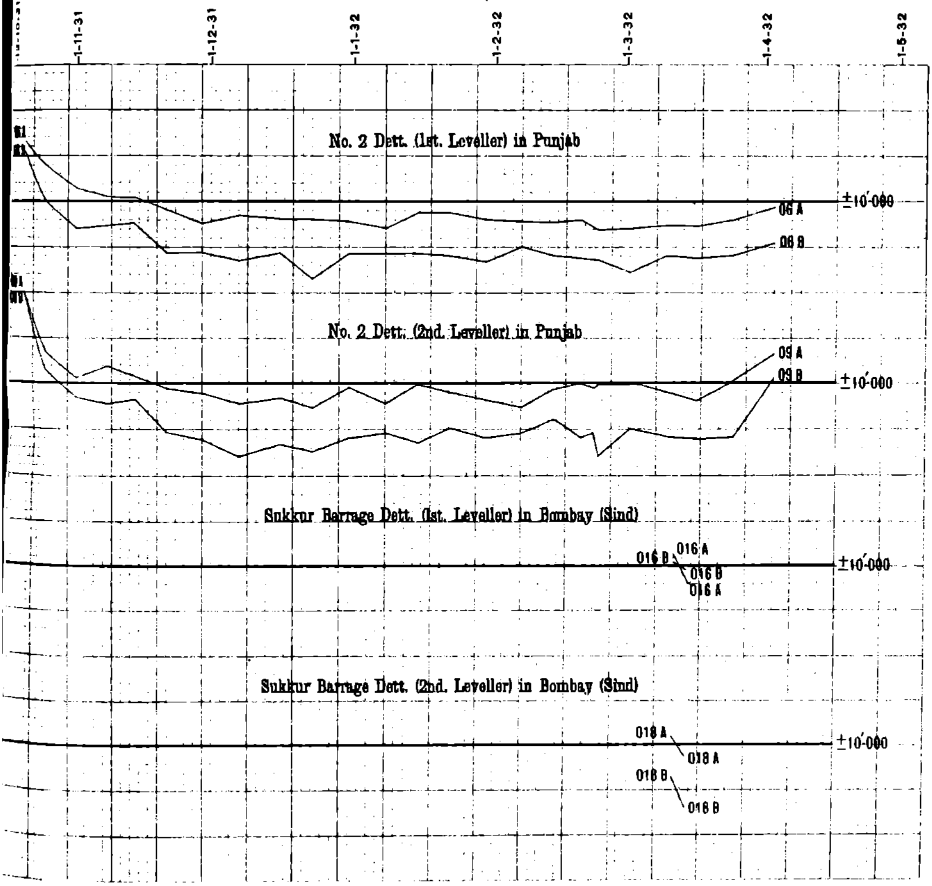
† Old numbers of B. Ms. which have received revised heights, the old numbers being shown in brackets.

7. Invar Staves. Invar staves fitted with steadying poles have now been introduced for Precise Levelling. Their consistency in length has obviated the continuance of the policy of weekly comparisons against a field standard tape, which is necessary when using wooden staves. The use of steadying poles, in stead of guying the staves, makes for increased out-turn. They have been fitted with bubbles on the side of the staff, of which one is always visible to the observer at the moment of reading. This ensures a verticality within 30 minutes of the true perpendicular (corresponding to a displacement of 1 inch at the top of the staff). Experiments with a staff fitted with a more sensitive graduated bubble show that the average displacement is well under 0·5 inches—a figure which even the extreme displacements recorded seldom exceeded.

Plate XVII

LENGTH OF LEVELLING STAVES, 1931-32

Vertical Scale 1 Small Square = 0·0005 foot



Reg. No. 10 D. D.D.1932

Helio. S.I.O. Dehra Dun

To accompany Geodetic Report Vol. VIII

TABLE 1.—*Tabular statement of out-turn of work, season 1931-32.*

Detachments and lines levelled	Months	Distance levelled			Total number of feet		Mean number of stations at which the instruments were set up	Number of bench marks connected		
								Primary		
		Main-line	Extras and branch-lines	Total	Rises	Falls		Rock-cut Protected	Other Primary	Secondary
		Mls.	Mls.	Mls.	feet	feet				
No. 1 Detachment.										
Branch-line 75 F Chāribātia-Kendrāpāra	Nov. 31 to Dec. 31	89	13	102	459	455	975	...	...	55
Branch-line 75 G Kiarbank-Puri	Dec. 31 to Jan. 32	89	6	95	710	704	986	...	...	70
Branch-line 39 B Puri-Puri	Jan. 32 to Feb. 32	89	5	94	1,007	1,024	1,016	...	...	76
No. 2 Detachment.										
Branch-line 57 S Bhiwāni-Bahādurgarh	Oct. 31 to Nov. 31	78	2	80	459	409	760	...	1	70
Branch-line 57 T Hānsi-Bhatinda	Nov. 31 to Dec. 31	136	4	140	716	715	1,270	...	...	159
Branch-line 57 U Mānsa-Sohūwāla	Dec. 31 to Jan. 32	41	10	51	257	316	456	...	...	41
Branch-line 57 V Badopāl-Narwāna	Jan. 32	47	20	67	337	352	648	...	1	54
Branch-line 57 W Narwāna-Rājpura	Jan. 32 to Feb. 32	91	21*	112	679	561	1,010	...	...	122
Branch-line 61 K Chandigarh-Dorāha	Feb. 32 to Mar. 32	72	10	82	932	934	872	...	...	113
Branch-line 57 X Dorāha-Patiāla	Mar. 32 to April 32	42	1	43	312	327	432	...	...	59
Sukkur-Barrage Detachment.										
Branch-line 52 M Standard B. M. at Sukkur to Barrage road bridge, Sukkur	March 32	4	...	4	107	146	90	1	1	10

* Includes 3 miles and 34 chains of relevelment.

CHAPTER VII

RESEARCH AND TECHNICAL NOTES

BY B. L. GULATEE, M.A.

I. Secular change of Himalayan Heights

1. During the period 1905–09, observations were made by Mr. H. G. Shaw to determine the heights of certain snow peaks, with a view to watch any possible rise of the Himālaya mountains. These observations are now being repeated after a lapse of about 25 years.

At the same time, the opportunity was taken to obtain further material for the analysis of the discrepancy which exists between the values obtained for the height of Mussoorie above Dehra Dūn, as determined by spirit-levelling and direct vertical angles.

In March 1932, Mr. M. N. A. Hashmie observed vertical angles from Camels' Back h. s. (Mussoorie) to Dehra refraction station, Nāg Tibba H. S., and also to the snow peaks Bandarpūnch, Srikānta, Jaonli and Kedārnāth. The instrument used was 12-inch Theodolite No. II, in which the zero of the vertical circle can be altered. The eye-piece micrometer was arranged for reading vertical angles, and three micrometer intersections were taken at each observation.

It was intended to make two sets of observations to each peak every day, each set on five zeros; this was not, however, possible in the case of the snow peaks, for visibility was bad and the peaks were covered in cloud most afternoons.

Vertical angles were observed with the Wild precision theodolite from Dehra refraction station to Camel's Back h. s., simultaneously with those taken from Mussoorie.

2. Data. The following table gives the data for the stations and peaks under observation :

Name of station	Latitude	Longitude	Orthometric S. L. height	Meridian deflection	Prime vertical deflection
	° ′ ″	° ′ ″	feet	″	″
Mussoorie Refraction Station ...	30 27 40·38	78 04 17·60	6930·65	−36·5	−25·5
Camel's Back h. s. ...	30 27 36·35	78 04 31·21	7022·71	−36·3	−25·2
Dehra Refraction Station ...	30 19 28·52	78 03 23·04	2234·325	−37·5	−19·5
Nāg Tibba H.S.	30 35 11·09	78 09 09·57	...	...	−23·5
Bandarpūnch	31 00 12·1	78 33 17·1			
Srikānta	30 57 25·2	78 48 22·0			
Jaonli	30 51 17·4	78 51 25·4			
Kedārnāth	30 47 53·0	79 04 07·0			

3. Changes in heights of snow peaks. As observations at the time of minimum refraction (2 to 3 p.m.) were not possible on account of weather, it was decided to use those observations which fell within half an hour of noon ; these were reduced to standard temperature (60°) and standard pressure (23·30 inches).

To avoid refraction uncertainties, these observations were compared with those taken by Shaw at the same hour during the months of March and April 1907 and 1908 ; sufficient observations conforming to these limits had not been taken in 1905, 1906 and 1909.

The results are as follows :

Differences of Height in Feet.

Year	Bandarpūnch	Srikānta	Jaonli	Kedārnāth	Nāg Tibba
1932 *minus* 1907	− 1·2	+ 4·4	− 1·8	+ 0·5	+ 0·2
1932 *minus* 1908	− 0·4	+ 3·9	− 1·9	− 3·7	0·0

The results show no evidence of a systematic change in the height of the peaks within the last 25 years. The differences given are probably due to refraction peculiarities or observation and graduation errors.

It is hoped that further observations will be undertaken in the early months of 1933.

4. Discrepancy in height of Mussoorie. Simultaneous reciprocal observations between Dehra Dūn and Mussoorie were taken on nine days. Taking into account the plumb-line deflections and adopting the same method of reduction as that used previously (*vide* Professional Paper No. 14, Chapter II), we find :

	feet
Difference of height between Dehra refraction station and Camel's Back h. s. ...	4798·21
Rise of Geoid	10·97
Difference by triangulation	4787·24
Difference by Spirit-levelling (1929-30) ...	4788·39
Triangulated height difference *minus* spirit-levelled height difference	− 1·15

This is rather large as compared with the previous discrepancy of +0·54 feet derived from Mr. Shaw's observations of 1905–09, on the assumption of the geoidal rise being 10·56 feet (see Geodetic Report Vol. VI, p. 73). Rigorous computation, however, gives the rise of the geoid between Dehra refraction station and Mussoorie refraction station to be 10·94 feet, which reduces the discrepancy still further to +0·16 feet.

The figures from Mr. Shaw's work are deduced from a larger number of observations spread over 5 years, whereas the 1932 observations are comparatively few, and so do not carry the same weight.

II. The Triangulation of Malaya, Indo-China, Dutch East Indies, Borneo and the Phillipine Islands.

1. This note is an outcome of inquiries addressed to the various governments in pursuance of the resolution passed at the triennial conference of the International Union of Geodesy and Geophysics at Stockholm in 1930, that Siam and neighbouring countries should collaborate with each other in effecting junctions between their systems of triangulation with the object of continuing, if possible, the chain of triangulation to the Australian Continent and the Phillipines.

Chart XXII (in pocket at end) gives triangulation of Malaya, the Dutch East Indies and the Phillipines.

2. Details of triangulation· A short account of triangulation of each country and the source from which it is derived is given below.

(*a*) *Malaya.* Triangulation is based on Everest's spheroid. Geodetic datum is at Kertau, Lat. N. 3° 27′ 53″·96, Long. E. 102° 37′ 24″·65, where plumb-line deflection is taken to be nil. There are 7 latitude and 3 azimuth stations. No longitudes have been observed. Accuracy of the triangulation is good, *m* being equal to about 0·6 seconds, and figures are quite well conditioned (*vide* Chart XVIII). Closure between bases on main chain was 1/50,000. The junction between Siamese and Malay triangulation has been planned, and will be completed by the end of 1932.

The above information is extracted from "An account of the Primary Triangulation of Malaya" by Victor A. Lowinger (29th April 1931).

(*b*) *Indo-China.* Primary Geodetic Triangulation of Indo-China consists of two meridional chains and six chains of parallel.

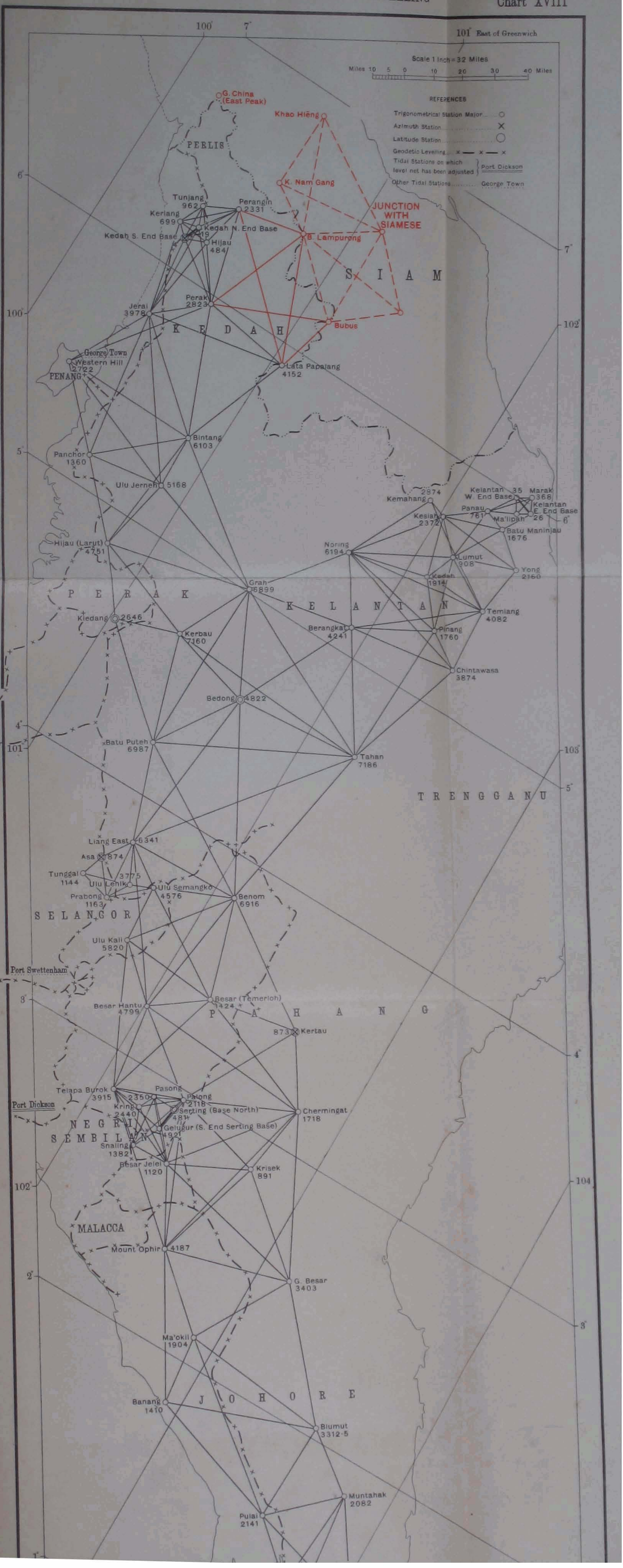
Clarke's 1880 ellipsoid has been chosen as the figure of reference.

Seven bases have been measured since 1899. The closure of check bases and common sides is of the order of 1/7,000 and differences of azimuths are as much as 80″. The large discrepancy in azimuth cannot be explained.

MALAYA

GEODETIC TRIANGULATION & LEVELLING

Chart XVIII



There are 4 astronomical stations.

Above information is extracted from "Etat d'Avancement des Travaux Geodesiques en Indochine" by General Mailles.

(*c*) *Dutch East Indies.* The triangulations of Sumatra and Java have been adjusted and form a continuous chain, the geodetic datum being at G. Genock.

The primary triangulation of Java was executed from 1861-80. Its *m* equals 1·8 seconds. There are 3 base-lines measured with Repsold apparatus, the mean probable error of each base being $0{\cdot}26 \times 10^{-6}$.

No geodetic astronomical work has been carried out. Bosscha Observatory at Lembang took part in the 1926 Longitude operations.

The triangulation of Sumatra (1883-1916) was adjusted in 1931, and is controlled by 2 base-lines measured by Jäderin apparatus. Its *m* equals 0·8 seconds.

There are 4 stations at which astronomical latitudes and azimuth have been observed very accurately. No longitudes have been observed. Bessel's ellipsoid has been used.

Small Soenda Archipelago (1912-18). Its primary triangulation system forms a continuation of the Java system, the accuracy of its angles being about the same as in the principal chain of Sumatra.

The above information has been taken from "Geodetic Survey in the Netherlands East Indies" by Prof. J. H. G. Schepers and Captain F. C. A. Schult.

Celebes Triangulation (1911). The triangulation is being adjusted; its accuracy is about the same as that of the principal chain of Sumatra. There are 3 base-lines and 4 latitude and azimuth stations.

Dutch Borneo. No primary triangulation exists, as the country is mostly swampy and covered with primeval forests. The necessary fixed points for surveying are determined astronomically.

British North Borneo. Primary triangulation was started in 1930. Two bases about 4 miles in length were measured at Tanan and Jesselton respectively and the angles of the extension nets were measured. The work had to be stopped on account of financial stringency.

(*d*) *Phillipine Islands.* There is no primary triangulation. Main triangulation which has been adjusted is secondary, controlled by 98 measured bases, 52 observed azimuth and 49 latitude and longitude stations.

Average triangular error does not exceed 3 seconds. Clarke's spheroid of 1866 is used, geodetic datum being at Luzon, Lat. 13° 33′ 41″·00 N., Long. 121° 52′ 03″·00 E. The project for connecting

Phillipine and N. Borneo is approved by the governments concerned, and the junction will be completed in 1932. Full details regarding the triangulation of Phillipine Islands are given in two volumes issued by the Department of Commerce and Communications Bureau of Coast and Geodetic Surveys.

(*e*) *Commonwealth of Australia.* No active progress is being made at the moment towards consummation of this work.

There is primary geodetic triangulation in New South Wales effected by 18-inch and 10-inch theodolites comprising about 300 triangles. Its *m* equals 0·5 seconds.

The other five states have their own individual surveys, but contain no triangulation of geodetic quality.

When the geodetic triangulation of Australia is started, it is proposed that basic work should be a chain of well-conditioned triangles traversing the commonwealth as a grid.

3. Conclusion. Chart XXII (in pocket at end) shows the progress of triangulation in the various countries. A connection between Malay States and Sumatra or Java seems to be very desirable.

It appears also that there is room for extending the Java and the Small Soenda Archipelago triangulation eastwards along Sumbawa, Flores and Timor. When this is done, we shall have a continuous chain of triangulation, starting from Lat. 30°, Long. 90° in India to Lat. 8° S., Long. 117° E. in Soenda Archipelago.

No connection exists between the Celebes triangulation and that of Java. The only possibility is through the islands in the Flores Sea, but it looks as if this junction will present some difficulties.

III. Extracts from Stokes' Gravity and Geoidal Paper.

This is a synopsis of Stokes' paper "On the variation of gravity at the surface of the earth" published in the Mathematical and Physical Papers, Vol. II, only those parts being abstracted as are necessary for a complete understanding of his formula for the rise of the geoid above its reference spheroid. Stokes' comments on the applicability of his formula to actual earth, and remarks as to how to deal with masses external to the geoid are also given.

Stokes established a general connection between the form of the geoid and variation of gravity on it without making any assumption about the distribution of matter in the interior of the earth. He says "it appears that if the form of the surface be given, gravity is determined throughout the whole surface except so far as regards one arbitrary constant which is contained in its complete expression and which may be determined by the value of gravity at one place."

"Let $r = a\,(1 + u)$ be the equation to the earth's surface where u is a small quantity of the first order, a function of θ and ϕ. Let u be expanded in a series of Laplace functions $u_0 + u_1 + \ldots$. The term u_0 will vanish provided we take for a, the mean radius or the radius of a sphere of equal volume". We may therefore take for the equation to the surface

$$r = a\,(1 + u_1 + u_2 + \ldots\ldots) \qquad \ldots \qquad \ldots \qquad \ldots \quad (8)$$

The attractional potential at all points external to the surface is given by

$$V = Y_0/r + Y_1/r^2 + \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (7)$$

At the points of the earth' surface, we have

$$V + \tfrac{1}{2}\,\omega^2\,r^2 \sin^2\theta = c \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (4)$$

We thus get from (4), (7), (8), omitting the squares of small quantities

$$V = Y_0\,\left(\frac{1}{r} + \frac{a}{r^2}\,u_1 + \ldots\right) - \frac{\omega^2 a^5}{2r^3}\left(\tfrac{1}{3} - \cos^2\theta\right) \qquad (10)$$

Let g be gravity at any point of the surface of the earth, dn an element of the normal drawn outwards at that point, and dr an element of radius vector, then

$$g = -\frac{d}{dn}\,(V + \tfrac{1}{2}\,\omega^2\,r^2 \sin^2\theta) \doteqdot -\frac{d}{dr}\,(V + \tfrac{1}{2}\,\omega^2\,r^2 \sin^2\theta).$$

"We thus get

$$g = \frac{Y_0}{a^2}(1 - 2u_1 - \ldots) + \frac{Y_0}{a^2}\,(2u_1 + 3u_2 + \ldots)$$
$$- \tfrac{3}{2}\,\omega^2 a\,(\tfrac{1}{3} - \cos^2\theta) - \omega^2 a\,(1 - \cos^2\theta),$$

which gives on putting

$$\left.\begin{aligned} \frac{Y_0}{a^2} - \tfrac{2}{3}\,\omega^2 a &= G \\ \omega^2 a/G &= m \end{aligned}\right\} \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \quad (11)$$

and neglecting squares of small quantities

$$g = G\left\{1 - \tfrac{5}{2}m\,(\tfrac{1}{3} - \cos^2\theta) + u_2 + 2u_3 + \ldots\right\} \ldots \quad (12)$$

In this equation, G is the mean value of g taken throughout the whole surface since we know that

$$\int_0^{\pi}\int_0^{2\pi} u_n \sin\theta\,d\theta\,d\phi = 0,\ \text{if } n \text{ be different from zero}".$$

"Equation (12) makes known the variation of gravity when the form of the surface is given, the surface being supposed to be one of equilibrium; and conversely, equation (8) gives the form of the surface if the variation of gravity be known.

If we suppose that the surface of the earth may be represented with sufficient accuracy by an oblate spheroid of small ellipticity having its axis of figure coincident with the axis of rotation, equation (8) becomes

$$r = a \left\{ 1 + \epsilon \left(\tfrac{1}{3} - \cos^2 \theta \right) \right\} \quad \ldots \quad \ldots \quad \ldots \quad (14)$$

where ϵ is a constant which may be considered equal to the ellipticity; we have, therefore in this case $u_1 = 0$, $u_2 = \epsilon \left(\frac{1}{3} - \cos^2 \theta \right)$, $u_n = 0$, when n is greater than 2, so that (12) becomes

$$g = G \left\{ 1 - \left(\tfrac{5}{2} m - \epsilon \right) \left(\tfrac{1}{3} - \cos^2 \theta \right) \right\} \quad \ldots \quad \ldots \quad (15)$$

which equation contains Clairaut's Theorem ".

Equation (7) will not give the value of the potential throughout the surface of a sphere which lies partly within the earth, because this satisfies the equation $\nabla^2 \ V = 0$ while in mass-filled space, V should satisfy $\nabla^2 \ V = -4 \pi \rho$.

" Nevertheless we may employ equation (7) for values of r, corresponding to spheres which lie partly within the earth, provided that in speaking of an internal particle, we slightly change the signification of V, and interpret it to mean not the actual potential, but what would be the potential if the protuberant matter were distributed within the least sphere which cuts the surface in such a manner as to leave the potential unchanged throughout the actual surface. The possibility of such a distribution will be justified by the result, provided the series to which we are led prove convergent ".

" Suppose the variation of gravity known by means of Pendulum experiments performed at a great many stations scattered over the surface of the earth and let it be required from the result of the observations to deduce the form of the surface. A series of Laplace's functions would most likely be practically useless for this purpose, unless we are content with merely the leading terms in the expansion for the radius vector; and the leading character of these terms depends, not necessarily upon their magnitude but only on the wide extent of the inequalities which they represent. We must endeavour therefore to reduce the determination of the radius vector to quadratures ".

By Clairaut's formula, we know that corresponding to

$$r_c = a \left\{ 1 + \epsilon \left(\tfrac{1}{3} - \cos^2 \theta \right) \right\},$$

we have $$g_c = G \left\{ 1 - \left(\tfrac{5}{2} m - \epsilon \right) \left(\tfrac{1}{3} - \cos^2 \theta \right) \right\}.$$

Put $$g = g_c + \Delta g, \ r = r_c + a \Delta u,$$

then by (8) and (12), if

$$\Delta g = G \sum_{n=2} v_n = G F(\theta, \phi) \qquad \dots \qquad \dots \qquad (42)$$

we shall have $\Delta u = \sum_{n=2} v_n/(n-1)$ ... ... (43)

Multiplying both sides of (42) by P_n we get

$$v_n = \left\{ (2n+1)/4\pi \right\} \int_0^{\pi} \int_0^{2\pi} F(\theta', \phi')\, P_n \sin\theta'\, d\theta'\, d\phi'$$

substituting for v_n in (43), we get

$$4\pi\, \Delta u = \int_0^{\pi} \int_0^{2\pi} F(\theta', \phi') \left[\Sigma \left\{ \frac{(2n+1)}{(n-1)} \right\} P_n \right] \sin\theta'\, d\theta'\, d\phi' \qquad (44)$$

we want now to find an expression for the sum of the infinite series

$$S = \Sigma \left\{ (2n+1)/(n-1) \right\} P_n$$

Consider the series $\gamma = \Sigma \left\{ (2n+1)/(n-1) \right\} \zeta^{n-1} P_n$

$$\frac{d\gamma}{d\zeta} = \Sigma\, (2n+1)\, \zeta^{n-2} P_n.$$

Let ψ be the angle between the directions determined by the angular co-ordinates (θ, ϕ) and (θ', ϕ'), then

$$1/(\sqrt{1 - 2\zeta\cos\psi + \zeta^2}) = P_0 + P_1\zeta + P_2\zeta^2 + \dots\dots$$

therefore, $\frac{1}{2}\int_0^{\zeta} \zeta^{\frac{3}{2}} \frac{d\gamma}{d\zeta}\, d\zeta = \sqrt{\zeta}\,[1/(\sqrt{1-2\zeta\cos\psi+\zeta^2}) - P_0 - P_1\zeta]$
$= \sqrt{\zeta}\, Z$ (say)

Differentiating we get $\frac{1}{2}\zeta^{\frac{3}{2}} \frac{d\gamma}{d\zeta} = \frac{d}{d\zeta}(Z\sqrt{\zeta})$.

therefore, $\gamma = 2Z/\zeta + 3\int_0^{\zeta} (Z/\zeta^2)\, d\zeta$,

$$S = \gamma_{\zeta=1} = 1/\sin\tfrac{1}{2}\psi - 2(1+\cos\psi) + 3\int_0^1 (Z/\zeta^2)\, d\zeta.$$

$$= \operatorname{cosec}\tfrac{1}{2}\psi + 1 - 6\sin\tfrac{1}{2}\psi - 5\cos\psi$$
$$- 3\cos\psi \log\left\{ \sin\tfrac{1}{2}\psi\,(1 + \sin\tfrac{1}{2}\psi) \right\}.$$

In the expression for Δu, we may suppose the line from which θ' is measured to be the radius vector of the station considered. Let the angles ψ, χ be with reference to the station considered what θ, ϕ were with reference to the North Pole, then

$$\Delta u = \frac{1}{4\pi G}\int_0^{\pi}\int_0^{2\pi} \Delta g\, f(\psi) \sin\psi\, d\psi\, d\chi \qquad \dots \qquad (46),$$

where $f(\psi) = \operatorname{cosec}\tfrac{1}{2}\psi + 1 - 6\sin\tfrac{1}{2}\psi - 5\cos\psi$
$- 3\cos\psi \log\left\{ \sin\tfrac{1}{2}\psi\,(1 + \sin\tfrac{1}{2}\psi) \right\}.$

Knowing Δg over whole globe, we can get Δu by a simple process of summation.

It has been shown by Mr. G. P. Rao, that if Δu is known, then determination of Δg can also be reduced to quadratures.

Thus corresponding to $\Delta u = \Sigma\, u_n$,

we have $\Delta g = G\,\Sigma\,(n-1)\,u_n$.

$$u_n = \left\{ (2n+1)/4\pi \right\} \int_0^{\pi}\int_0^{2\pi} \Delta u\, P_n \sin\theta'\, d\theta'\, d\phi',$$

therefore, $\Delta g = G/4\pi \int_0^{\pi}\int_0^{2\pi} \Delta u\, [\Sigma\,(2n+1)\,(n-1)\,P_n] \sin\theta'\, d\theta'\, d\phi'$.

We want to sum the series

$$S = \Sigma\,(2n+1)\,(n-1)\,P_n.$$

Starting from the identity

$$\sum_2^n P_n\,\zeta^n = 1/(\sqrt{1-2\,\zeta\cos\psi+\zeta^2}) - P_0 - P_1\,\zeta,$$

and multiplying both sides by $\zeta^{\frac{1}{2}}$ and differentiating we get

$$\tfrac{1}{2}\,\Sigma\,(2n+1)\,P_n\,\zeta^{n-\frac{1}{2}} = \sqrt{\zeta}\,(\cos\psi-\zeta)/\left\{(1-2\,\zeta\cos\psi+\zeta^2)^{\frac{3}{2}}\right\}$$

$$+\ 1/\left\{2\sqrt{\zeta}\,(1-2\zeta\cos\psi+\zeta^2)^{\frac{1}{2}}\right\} - \frac{1}{2\sqrt{\zeta}} - \tfrac{3}{2}\sqrt{\zeta}\cos\psi.$$

Multiply both sides of the above equation by $\zeta^{-\frac{1}{2}}$ and differentiate, and then put $\zeta = 1$.

We get $S = (1 - \tfrac{1}{4}\,\mathrm{cosec}^3\,\tfrac{1}{2}\psi)$.

$$\text{Hence } \Delta g = G/4\pi \int_0^{\pi}\int_0^{2\pi} \Delta u\,(1-\tfrac{1}{4}\,\mathrm{cosec}^3\,\tfrac{1}{2}\psi)\sin\psi\, d\psi\, d\chi \quad (47)$$

It might be noticed that at the origin $\psi = 0$, the integrand becomes $-\propto$.

As regards the applicability of his formulæ to earth, Stokes says "Hitherto the surface of the earth has been regarded as a surface of equilibrium. This we know is not strictly true. The question now arises, by what imaginary alteration shall we reduce the surface to one of equilibrium?" The surface of the sea, supposed to be prolonged under the continents by means of canals "forms indeed a surface of equilibrium but the preceding investigation does not apply directly to this surface, in as much as a portion of the attracting matter lies outside it. Conceive however the land which lies above the level of the sea to be depressed till it gets below it, or which is the same, conceive the land cut off at the level of the sea produced, and suppose the density of the earth or rock which lies immediately below the sea-level to be increased till the increase of mass immediately below each superficial element is equal to the mass which has been removed from above it. The whole of the attracting matter will thus be brought inside the original sea-level and it is easy to see that the attraction at a point of space external to the earth, even though it be close to the surface, will not be sensibly affected. Neither will the sea-level be sensibly changed, even in the middle of a continent".

"The surface of equilibrium which by the imaginary displacement of matter just considered has also become the bounding surface is that surface which at the same time coincides with the surface of the actual sea, where the earth is covered by water and belongs to the system of surfaces of equilibrium which lie wholly outside the earth. To reduce observed gravity to what would have been observed just above this imaginary surface we must evidently increase it in the inverse ratio of the square of the distance from the centre of the earth, without taking account of the attraction of the table-land which lies between the level of the station and the level of the sea".

"Gravity reduced in this manner would, however be liable to vary irregularly from one place to another, in consequence of the attraction of the land between the station and the surface of the sea". "To render our observations comparable with one another, it seems best to correct for the attraction of the land which lies underneath the Pendulum". Stokes proves however that the omission of this correction produces no sensible increase in the value of ellipticity ϵ, "unless the land be on the whole higher, or the sea shallower in high latitudes than in low".

It would be of interest to give Stokes' definition of ellipticity of the earth, "for, when the irregularities of the surface are taken into account, the term must be to a certain extent conventional".

Let the earth be $r = a\ (1 + u_2 + u_3 + \ldots\ldots\ldots)$. (The term u_1 can be made to disappear by taking origin at the centre of gravity of volume).

The surface $r = a\ (1 + u_2)$ represents an ellipsoid, and if its principal axes are taken as co-ordinate axes, then u_2 must be of the form $\epsilon_1 \cos 2\phi \sin^2\theta + \epsilon\ (\frac{1}{3} - \cos^2\theta)$.

The earth being nearly an oblate spheroid, ϵ_1 will be small and "ϵ is the constant, which determines the effect of earth's oblateness on the motion of the moon". This constant is called the ellipticity of the earth.

PUBLICATIONS

OF THE

SURVEY OF INDIA

(Corrected up to 31st December 1932)

PUBLICATIONS

OF THE

SURVEY OF INDIA

Obtainable from the Director, Geodetic Branch, Survey of India,
Dehra Dūn, U.P.

SYNOPSIS

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* **Publications detailed in Parts III, IV and V are also obtainable from the Officer in charge Map Record, and Issue Office, 13, Wood Street, Calcutta.**

Sterling Prices of Publications. The prices to be charged for Survey of India publications in sterling equivalents in English money have been worked out under the rules given in letter No. A-401 dated the 17th January 1924 from the Under Secretary to the Government of India, Department of Industries and Labour, Delhi, to the Secretary to the High Commissioner for India, General Department, 42 Grosvenor Gardens, London, S.W. 1. These sterling prices are subject to fluctuation with the exchange rate and will be revised from time to time. The prices at the current rate of exchange are:

Price in Indian money		English equivalent		Price in Indian money		English equivalent	
Rupees	Annas	Shillings	Pence	Rupees	Annas	Shillings	Pence
0	2	0	3	4	8	7	6
0	4	0	5	5	0	8	3
0	8	0	10	5	8	9	0
0	12	1	3	6	0	9	9
1	0	1	9	6	8	10	6
1	2	1	11	7	0	11	6
1	8	2	6	7	8	12	0
1	12	3	0	8	0	13	6
2	0	3	6	8	8	14	6
2	8	4	6	9	0	15	0
3	0	5	3	9	8	16	0
3	8	6	0	10	0	16	6
4	0	6	9	10	8	17	6
4	4	7	3	12	0	19	6

PART I. NUMERICAL DATA

Triangulation Pamphlets. Each covering one square degree, giving descriptions, positions, (latitude and longitude) and heights of triangulated points and other data with chart. The chart shows the plan of triangulation with the position of stations and points. Triangulation data falling in 1/M sheet are printed in a series of sixteen pamphlets A to P. In the last pamphlet of every series, a coloured map is given in addition to the chart, to illustrate the topographical features of the area covered by the 1/M sheet. Pamphlets having this map are charged Rs. 1-8 extra.

Charts Nos. XIX & XX at the end of the Geodetic Report shew what triangulation pamphlets have been published.

Price Re. 1 per pamphlet. Published at Dehra Dūn.

Levelling Pamphlets.

(i) **Levelling of Precision.** Giving heights and descriptions of all Bench marks fixed by Levelling of Precision and of certain selected secondary lines. Each pamphlet embraces an area of 4° × 4° and the numbering is the same as that of the corresponding sheets of the 1/M map of India. Each is illustrated by a map of the area. Published at Dehra Dūn.

(a) **Levelling of Precision in India and Burma.**

Pamphlet		Latitude N.	Longitude E.	Published in	Price
Sheet	Distinctive name of sheet				
34	(Quetta)	28°–32°	64°–68°	1916	Rs. 2-0-0
35	(Karāchi)	24–28	64–68	1911	Rs. 2-0-0
38	(Kābul)	32–36	68–72	1912	Rs. 2-0-0
39	(Multān)	28–32	68–72	1913	Rs. 2-0-0
	Addendum to 39 ...	...	...	1916	Rs. 2-0-0
40	(Hyderābād, Sind) ...	24–28	68–72	1911	Rs. 2-0-0
41	(Rājkot)	20–24	68–72	1913	Rs. 2-0-0
43	(Srīnagar)	32–36	72–76	1913	Rs. 2-0-0
	Addendum to 43 ...	...	...	1915	Rs. 2-0-0
44	(Lahore)	28–32	72–76	1926	Rs. 3-0-0
45	(Ajmer)	24–28	72–76	1911	Rs. 2-0-0
46	(Baroda)	20–24	72–76	1912	Rs. 2-0-0
47	(Bombay)	16–20	72–76	1912	Rs. 2-0-0
	Addendum to 47, Island of Bombay ...	...	...	1915	Re. 1-0-0
48	(Goa)	12–16	72–76	1912	Rs. 2-0-0
49	(Calicut)	8–12	72–76	1911	Re. 1-0-0
52	(Leh)	32–36	76–80	1912	Re. 1-0-0
53	(Delhi)	28–32	76–80	1929	Rs. 3-0-0
	Addendum to 53 ...	...	...	In the press.	
54	(Agra)	24–28	76–80	1930	Rs. 3-0-0
55	(Nāgpur)	20–24	76–80	1912	Rs. 2-0-0
56	(Hyderābād, Deccan) ...	16–20	76–80	1931	Rs. 2-0-0

Levelling Pamphlets—(*Continued*).

Pamphlet		Latitude N.	Longitude E.	Published in	Price
Sheet	Distinctive name of sheet				
57	(Mysore)	12°–16°	76°–80°	1919	Rs. 2-0-0
58	(Ootacamund) ...	8–12	76–80	1914	Rs. 2-0-0
62	(Mānasarowar) ...	28–32	80–84	1922	Re. 1-0-0
63	(Allahābād) ...	24–28	80–84	1923	Rs. 2-0-0
64	(Raipur)	20–24	80–84	1912	Rs. 2-0-0
65	(Vizagapatam) ...	16–20	80–84	1913	Rs. 2-0-0
66	(Madras)	12–16	80–84	1912	Rs. 2-0-0
72	(Kātmāndu) ...	24–28	84–88	1930	Rs. 2-0-0
73	(Cuttack)	20–24	84–88	1913	Rs. 2-0-0
	Addendum to 73 ...	...	...	1927	Rs. 2-0-0
74	(Puri)	16–20	84–88	1913	Rs. 2-0-0
78	(Darjeeling) ...	24–28	88–92	1923	Rs. 2-0-0
79	(Calcutta) ...	20–24	88–92	1924	Rs. 2-0-0
83	(Dibrugarh) ...	24–28	92–96	1912	Rs. 2-0-0
84	(Akyab)	20–24	92–96	1918	Rs. 2-0-0
85	(Prome)	16–20	92–96	1917	Rs. 2-0-0
92	(Bhamo)	24–28	96–100	1918	Rs. 2-0-0
93	(Mandalay) ...	20–24	96–100	1917	Rs. 2-0-0
94	(Rangoon) } ...	16–20	96–100	1916	Rs. 2-0-0
95	(Mergui) }	12–16	96–100		

(b) Levelling of Precision in Mesopotamia.

Descriptions and heights of bench marks in Mesopotamia in one pamphlet, published at Dehra Dūn, 1923. *Price Rs. 3*

(ii) Levelling of Secondary Precision.

Descriptions and heights of bench marks, printed by Gestetner at Dehra Dūn.

Levelling Pamphlets—(*Continued*).

Serial No.	Line number	Situated in degree sheets	Published in	Price
5	52E (Rohri to Jām Sahib) ...	40 A, B & E	1928	As. 6
6	52F (Shāhpur to Mīrpur Purāna)...	40 B, C & G	”	”
7	52G [Lāndhi canal bungalow (39th mile) to Khipro] ...	40 C & G	”	”
8	52H (Khipro to Ghulām Bhurgari)	40 G	”	”
9	52 I (Mīrpur Khās to Tando Ghulām Ali via Umarkot and Dādāh) ...	40 C, D, G & H	”	”
10	52J (Mīrpur Khās to Tando Ghulām Ali via Dīgri) ...	40 G	”	”
11	52K (Dīgri to Dādāh) ...	40 G & H	”	”
12	70J (Barākar to Hazāribāgh Road)	73 I and 72 H & L	”	As. 12
13	74C (Howrah to Uttarpāra) 74D (Baidyabāti to Sheorāphūli) 74E (Bāndel Church to Bāndel Ry. Stn.) 74F [B.M. 251(*118*)/79A to Pandua Ry. Stn.]	79 A & B	”	As. 8
14	74G (B.M. 126/73M to Saktigarh Ry. Stn.) 74H (B.M. 116/73M to Burdwān Ry. Stn.) 70E (B.M. 85/73M to Mānkar Ry. Stn.) 70F (B.M. 76/73M to Pānagar Ry. Stn.) 70G (B.M. 58/73M to Durgāpur Ry. Stn.) 70H (B.M. 28/73M to Rānīganj Ry. Stn.) 70 I (B.M. 15/73M to Asansol, Kālīpāhari & Churulia) 70M (Khāna Ry. Stn. to Galsi Ry. Stn.)	73 I & M	”	As. 12
15	77Q (Calcutta to Nārāyanpur) 77R (Nārāyanpur to Nārāyanpur)	79 B	”	Re. 1
16	87A (Moulmein to Paan) 87B (Moulmein to Wekali) 87C (Babukon to Kawmyatkyi) 87D (Nyaungbinzeik to Natchaung)	94 H & L and 95 E & I	”	As. 12

Levelling Pamphlets—(*Continued*).

Serial No.	Line number	Situated in degree sheets	Published in	Price
17	88B (Kyauktaga to Myitkyo) 88C (Dalanun to Pazuumyaung) 88D (Pegu to Zenyaungbin) 88E (Myitkyo to Okpo) 88F (E. B. M. at R. D. 25 of the Yenwe Embankment to Uaw) 90A (Nyaungzaye to Kandin) 90B (Ma-ubin to Bassein) 90C (Sagamya to Pantanaw) 90E (Thonze to Rangoon)	85 L,N,O & P and 94 B,C & D	1928	Rs. 2
18	89A (Kyaukse to Minzu) 89B (Ywakainggyi to Amarapura) 89C (Kyaukse to Mandalay) 89D (Tangôn to Shwebo) 89E (Kabo to Myittaw) 89F (Okshitkan to Paukkan) 90D (Meiktila to Yewe)	93 B & C. and 84 M,N, O & P	"	Rs. 1-8
19	29C (Nīra to Batgarh) ...	47 F & J	1929	As. 6
20	53A (Madad Chāndia to Mehar)	35 M	"	"
21	54B (Shikārpur to Kambar) ...	40 A	"	"
22	54C (Wāriāso to Rato-dero) ...	34 P,35 M, 39 D and 40 A.	"	"
23	55I (Garh Mahārāja to Damāmia)	39 N,44 A&B	"	"
24	55K (Aherbela to Multān) 55L (Rangpur to Muzaffargarh) 55M (Muzaffargarh to Basti Maluk)	39 N & O	"	As. 10
25	55O (Sujābād to Sabuwāli) ...	39 O	"	As. 6
26	55P (Jabboāna to Kot Māldeo) ...	44 A	"	"
27	56H (Kasūr to Basirpur) ...	44 F, I & J	"	"
28	57D (Lodhrān to Bahāwalpur) ...	39 O	"	"
29	57H (Basirpur to Lodhrān) ...	39 O, 44 B,C & F	"	"
30	57J (Kutabpur to Adamwāhān) ...	39 O	"	"
31	57L (Dīngarh to Khānpur) ...	39 L,O & P	"	"
32	57M (Mithra to Khānpur) ...	39 H & L and 40 E & I	"	"
33	57N (Chachran to Khānbela) ...	39 K,L & O	"	"
34	74B (Kidderpore to Dublat) ...	79 B	"	"
35	77V (Hastings Bridge to Dakhineswar) ...	79 B	"	"

Levelling Pamphlets—(*Concluded*).

Serial No.	Line number	Situated in degree sheets	Published in	Price
36	70K (Allahābād to Barākar) ...	63 G, K & O, 72 C, G,K&L and 73 I	1929	As. 14
37	70L (Mughal Sarāi to Hazāribāgh Road) ...	63 O & P and 72 D & H	,,	As. 10
38	55N (Basti Maluk to Kabirwala)	39 N & O	1930	As. 6
39	55H (Abdul Hakīm to Garh Mahārāja) 55J (Damāmia to Ahar Bela)	39 N & 44 B	,,	As. 6
40	29D (Gotūr to Kalādgi) ...	47 L & P	1931	As. 8
41	29B (Nīra to Jhālki) ...	47 J.K & O	1930	As. 6

NOTE. See also pamphlets of "Levelling of Precision in India and Burma" pages 95 and 96, for certain selected lines of Secondary Precision.

Tide-Tables.

From 1881 to 1922 tidal predictions based on the observations of the Survey of India were published annually by the India Office, London. From 1923 the prediction and publication have been undertaken at Dehra Dūn by the Survey of India, and until 1930 were published as follows :

(1) A single volume styled "**The Major Series**" *priced Rs. 8.*

(2) **Combined Pamphlets** varying in *price from Rs. 1-2 to Rs. 1-8 per copy.*

(3) **Separate Pamphlets** for individual ports *priced As. 12 per copy.* (For names of these ports see Geodetic Report Volume V, pages 31-33).

Commencing from 1931, a new form of publication styled "**Tide-Tables of the Indian Ocean**" has been introduced *priced Rs. 3 per copy.* This comprises full tide-tables for the 40 Indian ports predicted by the Survey of India, and 22 other standard ports in the Indian Ocean and Far East, also for 6 English and Mediterranean ports. In addition, it contains the non-harmonic tidal constants and tidal differences for 470 ports and anchorages, and the harmonic tidal constants of about 170 important tidal stations, mainly in the Indian Ocean and Far East.

Separate Pamphlets of tide-tables have also been published for the following ports :

Bombay	... *price As. 12 per copy*	
Hooghly River	... ,, *Rs. 1-8*	,,
Rangoon River	... ,, *Rs. 1-2*	,,

PART II. GEODETIC WORKS OF REFERENCE

Everest's Great Arc Book.

1. An account of the Measurement of an Arc of the Meridian between the parallels of 18° 3′ and 24° 7′, by Captain George Everest, F.R.S. &c., East India Company, London, 1830. (Out of print).

2. An account of the Measurement of two Sections of the Meridional Arc of India, bounded by the parallels of 18° 3′ 15″, 24° 7′ 11″ and 29° 30′ 48″, by Lt.-Colonel G. Everest, F.R.S. and his assistants, East India Company, London, 1847. (Out of print).

3. Engravings to illustrate the above. London, 1847. (Out of print).

G.T.S. Volumes. Describing the operations of the Great Trigonometrical Survey.

Vol. I **The Standards of Measure and the Base-Lines**, also an Introductory Account of the early operations of the Survey, during the period of 1800-1830. Dehra Dūn, 1870. (Out of print).

Vol. II **History and General Description of the Reduction of the Principal Triangulation.** Dehra Dūn, 1879. (Out of print).

Vol. III **North-West Quadrilateral.** The Principal Triangulation, the Base-Line Figures, the Karāchi Longitudinal, NW. Himālaya, and the Great Indus Series. Dehra Dūn, 1873. (Out of print).

Vol. IV **North-West Quadrilateral.** The Principal Triangulation, the Great Arc Section 24°-30°, Rahūn, Gurhāgarh and Jogi-Tīla Meridional Series, and the Sutlej Series. Dehra Dūn, 1876. *Price Rs. 10-8.*

Vol. IVA **North-West Quadrilateral.** The Principal Triangulation, the Jodhpur and the Eastern Sind Meridional Series with the details of their Reduction and the Final Results. Dehra Dūn, 1886. *Price Rs. 10-8.*

Vol. V **Pendulum Operations**, details of, by Captains J. P. Basevi and W. J. Heaviside, and of their Reduction. Dehra Dūn and Calcutta, 1879. *Price Rs. 10-8.*

Vol. VI **South-East Quadrilateral.** The Principal Triangulation and Simultaneous Reduction of the following Series: Great Arc Section 18° to 24°, the East Coast, the Calcutta and the Bīdar Longitudinal, the Jubbulpore and the Bilāspur Meridionals. Dehra Dūn, 1880. (Out of print.)

Vol. VII **North-East Quadrilateral.** General Description and Simultaneous Reduction. Also details of the following five series: North-East Longitudinal, the Budhon Meridional, the Rangir Meridional, the Amua Meridional, and the Karāra Meridional. Dehra Dūn, 1882. *Price Rs. 10-8.*

Vol. VIII **North-East Quadrilateral.** Details of the following eleven series:

Gurwāni Meridional, Gora Meridional, Hurilāong Meridional, Chendwār Meridional, North Parasnāth Meridional, North Malūncha Meridional, Calcutta Meridional, East Calcutta Longitudinal, Brahmaputra Meridional, Eastern Frontier Section 23°-26°, and Assam Longitudinal. Dehra Dūn, 1882. *Price Rs. 10-8.*

G.T.S. Volumes—(*Concluded*).

Vol. IX **Telegraphic Longitudes.** During the years 1875-77 and 1880-81. Dehra Dūn, 1883. *Price Rs. 10-8.*

Vol. X **Telegraphic Longitudes.** During the years 1881-82, 1882-83, and 1883-84. Dehra Dūn, 1887. *Price Rs. 10-8.*

Vol. XI **Astronomical Latitudes.** During the period 1805-1885. Dehra Dūn, 1890. *Price Rs. 10-8.*

Vol. XII **Southern Trigon.** General Description and Simultaneous Reduction. Also details of the following two series: Great Arc Section 8°-18°, and Bombay Longitudinal. Dehra Dūn, 1890. *Price Rs. 10-8.*

Vol. XIII **Southern Trigon.** Details of the following five series: South Konkan Coast, Mangalore Meridional, Madras Meridional and Coast, South-East Coast, and Madras Longitudinal. Dehra Dūn, 1890. *Price Rs. 10-8.*

Vol. XIV **South-West Quadrilateral.** Details of Principal Triangulation and Simultaneous Reduction of its component series. Dehra Dūn, 1890. *Price Rs. 10-8.*

Vol. XV **Telegraphic Longitudes.** From 1885 to 1892 and the Revised Results of Volumes IX and X: also the Simultaneous Reduction and Final Results of the whole Operations. Dehra Dūn, 1893. *Price Rs. 10-8.*

Vol. XVI **Tidal Observations.** From 1873 to 1892, and the Methods of Reduction. Dehra Dūn, 1901. *Price Rs. 10-8.*

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.*

Vol. XVIII **Astronomical Latitudes.** From 1885 to 1905 and the deduced values of Plumb-line Deflections. Dehra Dūn, 1906. *Price Rs. 10-8.*

Vol. XIX **Levelling of Precision in India.** From 1858 to 1909. Dehra Dūn, 1910. *Price Rs. 10-8.*

Vol. XIXA **Bench Marks on the Southern Lines of Levelling.** Dehra Dūn, 1910. *Price Rs. 5.*

Vol. XIXB **Bench Marks on the Northern Lines of Levelling.** Dehra Dūn, 1910. *Price Rs. 5.*

PART III. HISTORICAL AND GENERAL REPORTS

Memoirs.

1. A Memoir on the Indian Surveys, by C. R. Markham, India Office, London, 1871. *Price Rs. 5.*
2. A Memoir on the Indian Surveys. (Second Edition), by C. R. Markham, C.B., F.R.S., India Office, London, 1878. *Price Rs. 5-8.*

Memoirs—(*Concluded*).

3. Abstract of the Reports of the Surveys and of other Geographical operations in India, 1869-78, by C. R. Markham and C. E. D. Black, India Office, London. Published annually between 1871 and 1879. (Out of print).
4. A Memoir on the Indian Surveys, 1875-1890, by C. E. D. Black, India Office, London, 1891. *Price Rs. 5-8.*

"Notes of the Survey of India" are issued monthly. *Price As. 2.*

Annual and Special Reports.

Annual Reports of the **Revenue Branch.** 1851 to 1877. (Out of print).
Ditto **Topographical Branch.** 1860 to 1877. (Out of print).
Ditto **Trigonometrical Branch.** 1861 to 1878. (1861 to 71, out of print). *Price Rs. 2.*

In 1878 the three branches were amalgamated, and from that date onwards annual reports in single volumes for the whole department, were published as follows:

General Reports	from 1877 to 1900.	*Price Rs. 3 per volume.*
	from 1900 to 1922.	*Price Rs. 2 per volume.*

From 1900 onwards the Report was issued annually in the form of a condensed statement known as (*a*) the "**General Report**" supplemented by fuller reports, which were called (*b*) "**Extracts from Narrative Reports**" up to 1909, and then (*c*) "**Records of the Survey of India**" until 1921.

From 1922 the annual reports are published in three separate volumes of octavo size, viz., (*a*) **General Report** which is confined to reporting the Survey operations of the ordinary field parties and detachments with only brief abstracts of Geodetic operations, Map Publication and Office work. Published annually *Price 1922-25 Rs. 2, from 1925 Re. 1.* (*d*) **Map Publication and Office Work** report which contains all the Index Maps showing the Progress of Map Publication on all scales, with reports on publication and issue. Published annually beginning with year 1924. *Price Re. 1.* (*e*) **Geodetic Report** which includes full details of all scientific work of the Geodetic Branch, Survey of India excluding the work of the Dehra Drawing Office and Publication Office.

These fuller reports are available as follows:

(*b*) **Extracts from Narrative Reports.**

1900-01. Recent Improvements in Photo-Zincography. G. T. Triangulation in Upper Burma. Experimental Base Measurement with Jäderin Apparatus. Topography in Upper Burma. Calcutta, 1903. (Out of print).

1901-02. G.T. Triangulation in Upper Burma. Topography in Upper Burma. Sind, Punjab. Calcutta, 1904. (Out of print).

1902-03. Principal Triangulation in Upper Burma. Topography in Upper Burma, Shan States. Survey of Sāmbhar Lake. Introduction of the Contract System of Payment in Traverse Surveys. Traversing with the Subtense Bar. Compilation and Reproduction of Thāna Maps. Calcutta, 1905. *Price Rs. 1-8.*

Annual Reports &c.—(*Continued*).

1903-04. Utilization of old Traverse Data for Modern Surveys in the United Provinces. Identification of Snow Peaks in Nepāl. Topographical Surveys in Sind. Notes on town and Municipal Surveys. Notes on Riverain Surveys in the Punjab. Calcutta, 1906. *Price Rs. 1-8.*

1904-05. Triangulation in Baluchistān. Survey Operations with the Somāliland Field Force. Calcutta, 1907. *Price Rs. 1-8.*

1905-06. Topography in Shan States. Calcutta, 1908. *Price Rs. 1-8.*

1906-07. Triangulation in Baluchistān. Topography in Shan States. Calcutta, 1909. *Price Rs. 1-8.*

1907-08. Topography in Shan States. Calcutta, 1910. *Price Rs. 1-8.*

1908-09. Calcutta, 1911. *Price Rs. 1-8.*

(*c*) **Records of the Survey of India.**

Vol. I **1909-10.** Calcutta, 1912. *Price Rs. 4.*

Vol. II **1910-11.** Calcutta, 1912. *Price Rs. 4.*

Vol. III **1911-12.** Calcutta, 1913. *Price Rs. 4.*

Vol. IV **1911-13.** Explorations on the North-East Frontier. North Burma, Mishmi, Abor and Miri Surveys. Calcutta, 1914. *Price Rs. 4.*

Vol. V **1912-13.** Note on the relationship of the Himālayas to the Indo-Gangetic Plain. Calcutta, 1914. *Price Rs. 4.*

Vol. VI **1912-13.** Link connecting the Triangulatons of India and Russia. Dehra Dūn, 1914. *Price Rs. 4*

Vol. VII **1913-14.** Note on Scales and cost rates of Town plans. Calcutta, 1915. *Price Rs. 4.*

Vol. VIII { **1865-79 Part I**
1879-92 Part II } Explorations in Tibet and neighbouring regions. Dehra Dūn, 1915. *Price of each part Rs. 4.*

Vol. VIII (A) **1914.** Explorations in the Eastern Kara-koram and the Upper Yārkand Valley, by Lt.-Colonel H. Wood, R.E. Dehra-Dūn, 1922. *Price Rs. 3.*

Vol. IX **1914-15.** Criterion of strength of Indian Geodetic Triangulation. A traverse signal for City Surveys. "The plains of Northern India and their relationship to the Himālaya Mountains" an address by Colonel S. G. Burrard, F.R.S. Report on Turco-Persian Frontier Commission. Calcutta, 1916. *Price Rs. 4.*

Vol X **1915-16.** Mechanical Integrator for calculating Attractions (illustrated). Traverse Survey of the boundary of Imperial Delhi. Dehra Dūn, 1917. *Price Rs. 4.*

Vol. XI **1916-17.** Triangulation; use of high trestle for stations and 100-foot mast signals. Note on Basevi's Pendulum Operations at Morê. Photo-Litho Office; New method of preparing Layer plates; Developments and Improvements in preparing Tint-plates. Dehra Dūn, 1918. *Price Rs. 4.*

Vol. XII Notes on Survey of India Maps and the modern development of Indian Cartography, by Lt.-Colonel W. M. Coldstream, R.E., Superintendent, Map Publication. Calcutta, 1919. *Price Rs. 3.*

Annual Reports &c.—(*Continued*).

Vol. XIII **1917-18.** Photo-Litho office; the Powder Process. Problem of the Himālayan and Gangetic Trough; Review by Dr. A. Morley Davies. Dehra Dūn, 1919. *Price Rs. 4.*

Vol. XIV **1918-19.** Levelling in Mesopotamia. Dehra Dūn, 1920. *Price Rs. 4.*

Vol. XV **1919-20.** Levelling; proposed new level net. The Earth's Axes and Figure, by J. de Graaff Hunter (a paper read at the R. A. S. Geophysical Meeting). Report on the expedition to Kamet. Note on the Topography of the Nun Kun Massif in Ladākh. Dehra Dūn, 1921. *Price Rs. 4.*

Vol. XVI **1920-21.** High Climbs in the Himālaya prior to the Everest Expedition. Mt. Everest Survey Detachment, 1921. Traverse Survey of Allahābād city. Settlement of Boundary between Mysore and South Kanara. Dehra Dūn, 1922. *Price Rs. 4.*

Vol. XVII **1923.** Memoir on Maps of Chinese Turkistān and Kansu from the Surveys made during Sir A. Stein's Explorations, 1900-01, 1906-08, 1913-15. Dehra Dūn, 1923. *Price Rs. 12.*

Vol. XVIII **1921-22.** Traverse Survey of Allahābād city. Settlement of Boundary between Mysore and South Kanara. Notes on Revision Survey in the neighbourhood of Poona. Dehra Dūn, 1923. *Price Rs. 4.*

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.*

Vol. XX **1914-20.** The War Record. Dehra Dūn, 1925 *Price Rs 3.*

Vol. XXI **1922-23-24.** I. Air Survey in the Irrawaddy Delta 1923-24, by Major C. G. Lewis, R.E., and II. Reconnaissance Survey in Bhutān and South Tibet 1922, by Captain H. R. C. Meade, I.A. Dehra Dūn, 1925. *Price Rs. 1-8.*

Vol. XXII **1926**—Exploration of the Shaksgam Valley and Aghil Ranges, 1926, by Major K. Mason, M.C., R.E. Dehra Dūn, 1928. *Price Rs. 3*

Vol. XXIII **1926-30.** Report on Sind Rectangulation, 1926-30, by Lt.-Colonel A. H. Gwyn, I. A. Dehra Dūn, 1932. *Price Rs. 1-8.*

(*e*) Geodetic Reports.

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.*

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.*

Annual Reports &c.—(*Concluded*).

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.*

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.*

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.*

Vol. VI **1929-30.** Computations and Publication of data. Observatories. Tides. Gravity. Triangulation. Levelling. Research and Technical Notes. Dehra Dūn, 1931. *Price Rs. 3.*

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.*

Vol. VIII **1931-32.** Computations and Publication of data. Observatories. Tides. Gravity. Triangulation. Levelling. Research and Technical Notes. Dehra Dūn. 1933. *Price Rs. 3.*

PART IV. CATALOGUES AND INSTRUCTIONS

Departmental Orders.

From 1878 to 1885 the Surveyor General's orders were all issued as "*Circular Orders*". Since then they have been classified as follows:

From 1885 to 1904 as
1. **Government of India Orders** (called "*Circular Orders*" up to 1898).
2. **Departmental Orders (Administrative)**
3. **Departmental Orders (Professional)**

In 1904 the various orders issued since 1878 were reclassified as follows:

		Number to date.
1.	**Government of India Orders.**	856
2.	**Circular Orders (Administrative).**	429
3.	**Circular Orders (Professional).**	196
4.	**Departmental Orders** (appointments, promotions, transfers etc.)	

These are numbered serially and had reached the above numbers by September 1932. *Government of India Orders and Circular Orders* (*Administrative*) are bound up in volumes from time to time, as shown below, while *Circular Orders* (*Professional*) are gradually incorporated in the Survey Handbooks. Besides the above, temporary orders have been issued since 1910 in the form of "**Circular Memos**". These either lapse or become incorporated in some more permanent form, and are therefore only numbered serially for each year. Bound volumes of orders are available as follows:

1. *Government of India Orders (Departmental) 1878-1903. Calcutta, 1904.
   ,, ,, 1904-1908. Calcutta, 1909. (Out of print).
   ,, ,, 1909-1913. Calcutta, 1915.
   ,, ,, 1914-1918. Calcutta, 1920.
   ,, ,, 1919-1924. Dehra Dūn 1929.

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Departmental Orders.—(*Concluded*).

2. *Circular Orders (Administrative) 1878-1903. . Calcutta, 1904.
" " 1904-1908. Calcutta, 1909.
" " 1909-1913. Calcutta, 1915.
" " 1914-1918. Calcutta, 1920.
" " 1919-1924. Dehra Dūn, 1926.

3. * Regulations on the subject of Language Examinations for Officers of the Survey of India. Calcutta, 1914.

4. * Map Publication Orders 1908-1914 (Superintendent, Map Publication's Orders.) Calcutta, 1914.

5. Specimens of papers set at Examinations for the Class II Service. Dehra Dūn, 1927 & 1929. *Price Re. 1* per year.

Catalogues and Lists.

1. **Catalogue** of Maps published by the Survey of India. Calcutta, 1931. *Price Re. 1.*

Lists of new maps published during each month appear in the monthly NOTES OF THE SURVEY OF INDIA. These monthly lists are also issued separately.

2. **Catalogue** of Maps of Burma. Calcutta, 1925. *Price As. 8.*

3. **Catalogue** of Maps of Cantonments and Military stations. Dehra Dūn, 1927. *Price As. 8.*

4. **Catalogue** of Books in the headquarters Library, Calcutta, 1901. (Out of print).

5. **Catalogue** of Scientific Books and Subjects in the Library of the Trigonometrical Survey Office. Dehra Dūn, 1908. *Price Re. 1.*

6. Classified **Catalogue** of the Trigonometrical Survey Library. Dehra Dūn, 1921. *Gratis*

7. **Green Lists.** Part I List of Officers in the Survey of India (annually to date 1st January. Supplementary Edition dated 1st July 1932), Calcutta. *Price Rs. 1-2.*
Part II History of Services of Officers in the Survey of India (annually to date 1st July. 1932 Edition not published), Calcutta. *Price Rs. 1-2.*

8. **Blue Lists.** Ministerial and Lower Subordinate Establishments of the Survey of India.
Part I Headquarters and Dehra Dūn offices (published annually to date 1st April. 1932 Edition published on 1st July), Calcutta. *Price Rs. 6-6.*
Part II Circles and parties (published annually to date 1st January. 1932 Edition published on 1st July), Calcutta. *Price Rs. 8-10.*

9. **List of the Publications of the Survey of India** (published annually) Dehra Dūn. *Gratis*

10. **Price List of Mathematical Instrument Office.** Corrected up to 1st September 1927. Calcutta, 1928. *Gratis.*

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Tables and Star Charts.

1. **Auxiliary Tables.** To facilitate the calculations of the Survey of India. Fourth Edition, Dehra Dūn, 1906. (Out of print).

2. **Auxiliary Tables.** Of the Survey of India. Fifth Edition, (revised and extended), by J. de Graaff Hunter, M.A., SC.D., F. INST. P. In parts—

Part I Graticules of Maps, (reprinted). Dehra Dūn, 1926. *Price Re. 1.*
Part II Mathematical Tables, (reprinted with additions). Dehra Dūn, 1931. *Price Rs. 2.*
Part III Topographical Survey Tables, (reprinted with additions). Dehra Dūn, 1928. *Price Rs. 3.*
Part IV Geodetic Tables, (A) Triangulation Tables. Dehra Dūn, 1931. *Price Re. 1.*

3. Tables for Graticules of Maps. Extracts for the use of **Explorers.** Dehra Dūn, 1918. *Price As. 4.*

4. * Metric Weights and Measures and other tables. Photo-Litho Office. Calcutta, 1889.

5. Logarithmic Sines and Cosines to 5 places of decimals. Dehra Dūn, 1886. *Price As. 4.*

6. Logarithmic Sines, Cosines, Tangents and Cotangents to 5 places of decimals. Dehra Dūn, 1915. (Out of print).

7. Common Logarithms to 5 places of decimals, 1885. (Out of print).

8. Table for determining Heights in Traversing. Dehra Dūn, 1898. *Price As. 8.*

9. Tables of distances in Chains and Links corresponding to a subtense of 20 feet. Dehra Dūn, 1889. *Price As. 4.*

10. * „ „ 10 feet. Calcutta, 1915.

11. * „ „ 8 feet. „

12. Field Traverse Tables. First Edition. Calcutta, 1928. *Price As. 8.*

13. Star Charts for latitude 20° N., by Colonel J. R. Hobday, I.S.C. Calcutta, 1904. *Price Rs. 1-8.*

14. Star Charts for latitude 30° N., by Lt.-Colonel S. G. Burrard, R.E., F.R.S. Dehra Dūn, 1906. *Price Rs. 1-8.*

15. Star Charts for latitude 15° N. Dehra Dūn, 1928. *Price Rs. 2.*

16. Star Charts for latitude 30° N. Dehra Dūn, 1928. *Price Rs. 2.*

17. Catalogue of 249 Stars for epoch 1st Jan. 1892, from observations by the Survey, Dehra Dūn, 1893. *Price Rs. 2.*

18. * Rainfall, maximum and minimum temperatures, from 1868 to 1927, recorded at the Survey Office Observatory, Dehra Dūn, 1928.

19. * Booklet of conventional signs for use on Plane-table Sections. Second Edition, 1928.

Old Manuals.

1. A Manual of Surveying for India, detailing the mode of operations on the Revenue Surveys in Bengal, and the North-Western Provinces. Compiled by Captains R. Smyth, and H. L. Thuillier. Calcutta, 1851. (Out of print).

2. Ditto Second Edition. London, 1855. (Out of print).

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Old Manuals.—(*Concluded*).

3. A Manual of Surveying for India, detailing the mode of operations on the Trigonometrical, Topographical and Revenue Surveys of India. Compiled by Colonel H. L. Thuillier, C.S.I., F.R.S., and Lt.-Col. R. Smyth. Third Edition, revised and enlarged. Calcutta, 1875. (Out of print).

4. Hand-Book, Revenue Branch. Calcutta, 1893. *Price Rs. 2-8.*

Survey of India Hand-Books.

1. *** Hand-Book of General Instructions** (in 2 vols.) Fifth Edition. 1927.

2. **Hand-Book, Trigonometrical Branch,** Second Edition. Calcutta, 1902. (Out of print).

3. **Hand-Book of Trigonometrical Instructions.** Third Edition. Parts in pamphlet forms

Part I Geodetic Triangulation. First Edition. Dehra Dūn 1931. *Price Rs. 2-8.*
Part V The Tides. First Edition, revised, Dehra Dūn, 1926. *Price Rs. 2.*
Part VI Levelling. Second Edition, revised, Dehra Dūn, 1928. *Price Re. 1.*

4. **Hand-Book, Topographical Branch.** Third Edition. Calcutta, 1905. (Out of print).

5. **Hand-Book of Topography.** Fourth Edition. Calcutta, 1911. Chapters, in pamphlet forms

Chapter I Introductory. Fifth Edition 1932. *Price As. 8.*
„ II Constitution and Organization of a Survey Party. reprinted with additions, 1923. *Price As. 8.*
„ III Triangulation and its Computation. revised 1930. *Price Re. 1.*
„ IV Theodolite Traversing. Third Edition, 1927. *Price Re. 1.*
„ V Plane-tabling. Third Edition, 1926. *Price Re. 1.*
„ VI Fair Mapping. reprinted with additions and revised, (Sixth Edition) 1928. *Price Re. 1.*
„ VII Trans-Frontier Reconnaissance. Third Edition, 1924. *Price As. 8.*
„ VIII Surveys in War. Second Edition, 1930. *Price Re. 1.*
„ IX Forest Surveys and Maps. 1925. *Price As. 8.*
„ X Map Reproduction. Third Edition, 1928. *Price As. 8.*
„ XI Geographical Maps. Second Edition, 1926. *Price As. 8.*
„ XII Air Surveys (Provisional Edition). *At Press.*

6. ***Photo-Litho Office,** Notes on Organization, Methods and Processes, by Major W. C. Hedley, R.E. Third Edition. Calcutta, 1924.

7. **The Reproduction (for the guidance of other Departments) of Maps, Plans, Photographs, Diagrams, and Line Illustrations.** Calcutta, 1914. *Price Rs. 3.*

8. **Survey of India Copy Book of Lettering.** Calcutta. *Price Rs. 3-8.*

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Notes and Instructions.

Drawing and paper.

1. *Notes on Printing Papers suitable for Maps, and on Whatman Drawing Paper, by Major W. M. Coldstream, R.E. Calcutta, 1911. (Out of print).

Printing and Field Litho processes.

2. *Report on Rubber Offset Printing for Maps, by Major W. M. Coldstream, R.E. Calcutta, 1911.

3. *Notes on the "Vandyke" or Direct Zinc Printing Process, with details of Apparatus and Chemicals required for a small section. Compiled in the Photo and Litho Office, Survey of India. Calcutta, 1913. (Out of print).

4. *Notes on some of the Methods of Map Reproduction suitable for the Field with appendix—Suggested Equipment Tables for the Light Field Litho Press (experimental), by Lieut. A. A. Chase, R.E. Calcutta, 1911.

5. *Report on a trial of the equipment of the 1st (Prince of Wales' Own) Sappers and Miners, for reproducing maps in the field, by Lieut. A. A. Chase, R.E. Calcutta, 1912. (Out of print).

Base Lines and Magnetic.

6. *Notes on use of the Jäderin Base line Apparatus. Dehra Dūn, 1904. (Out of print).

7. *Miscellaneous Papers relating to the Measurement of Geodetic Bases by Jäderin Invar Apparatus. Dehra Dūn, 1912.

8. *Instructions for taking Magnetic Observations, by J. Eccles, M.A. Dehra Dūn, 1896. (Out of print).

9. **Rectangular Co-ordinates.** On a Simplification of the Computations relating to, by J. Eccles, M.A. Dehra Dūn, 1911. *Price Re. 1.*

10. ***For Explorers.** Notes on the use of Thermometers, Barometers and Hypsometers with Tables for the Computation of Heights, by J. de Graaff Hunter, M.A. Dehra Dūn, 1911. (Out of print).

11. *Amended Instructions for the Survey and Mapping of Town Guide Maps. August 1919.

12. *Notes on the map of Arabia and the Persian Gulf, with a general index of place names on the map, 1905-08, by Captain F. Fraser Hunter, I.A. Calcutta, 1910.

13. **Accounts Pamphlet.** Notes on accounts for field units. Dehra Dūn, 1928. *Price Re. 1.*

PART V. MISCELLANEOUS PAPERS

Unclassified Papers.

Geography.

1. A Sketch of the Geography and Geology of the Himālaya Mountains and Tibet (in four parts), by Colonel S. G. Burrard, R.E., F.R.S., Supdt., Trigonometrical Surveys, and H. H. Hayden, B.A., F.G.S., Supdt., Geological Survey of India. Calcutta, 1907-08. (*Second Edition at press*).

Part	I	The High Peaks of Asia.	*Price Rs. 2* per part.
,,	II	The Principal Mountain Ranges of Asia.	
,,	III	The Rivers of the Himālaya and Tibet.	
,,	IV	The Geology of the Himālaya.	

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Unclassified Papers.—(*Continued*)

2. *Report on the Identification and Nomenclature of the Himālayan Peaks as seen from Kātmāndu, Nepāl, by Captain H. Wood, R.E. Calcutta, 1904.

3. Routes in the Western-Himālaya, Kashmīr etc., by Lt.-Colonel T. G. Montgomerie, R.E., F.R.S., F.R.G.S. Dehra Dūn, 1909. (Out of print).

4. Routes in the Western-Himālaya, Kashmīr etc., with which are included Montgomerie's Routes. Volume I. Pūnch, Kashmīr and Ladākh, by Major Mason, M.C., R.E., Second Edition, Calcutta, 1929. *Price Rs. 6.*

Exploration.

1. *Account of the Survey Operations in connection with the Mission to Yārkand and Kashgar in 1873-74, by Captain Henry Trotter, R.E. Calcutta, 1875. (Out of print).

2. Report on the Trans-Himālayan Explorations during 1869. (Out of print).

3. Report on the Trans-Himālayan Explorations during 1870. Dehra Dūn, 1871. (Out of print).

4. Report on the Trans-Himālayan Explorations during 1878. Calcutta, 1880. (Out of print).

5. Where is it. Reference index showing geographical position of all important localities in INDIA and adjacent countries, in four parts. Calcutta, 1928.

Part I Place names. Cities, towns, and other sites.
„ II Railway stations. Complete list, 1928.
„ III Localities. Districts, States, Tribes etc.
„ IV Physical. Ranges, passes, peaks, glaciers, rivers, canals, lakes, bays, capes, islands etc.
Price As. 12.

6. Glossary of Vernacular Terms used in Survey of India Maps. Calcutta, 1931. *Price As. 5.*

Special Reports.

1. *Report on the Mussoorie and Landour, Kumaun and Garhwāl, Rānīkhet and Kosi Valley Surveys, extended to Peshāwar and Kāghān Triangulation during 1869-70, by Major T. G. Montgomerie, R.E. (Out of print).

2. Report on the Recent Determination of the Longitude of Madras, by Captain S. G. Burrard, R.E. Calcutta, 1897. (Out of print).

3. *Report on the Observations of the Total Solar Eclipse of 6th April, 1875 at Camorta, Nicobar Islands, by Captain J. Waterhouse. Calcutta, 1875. (Out of print).

4. *The Total Solar Eclipse, 22nd January, 1898. Dehra Dūn, 1898.
   (1) Report on the observations at Dumraon.
   (2) Report on the observations at Pulgaon.
   (3) Report on the observations at Sahdol.

5. *Report on Local Attraction in India, 1893-94, by Captain S. G. Burrard, R.E. Calcutta, 1895. (Out of print).

6. *Report on the Trigonometrical Results of the Earthquake in Assam, by Captain S. G. Burrard, R.E. Calcutta, 1898. (Out of print).

7. *Notes on the Topographical Survey of the 1/50,000 Sheets of Algeria by the Topographical Section of the "Service Geographique de l'Armée", by Captain W. M. Coldstream, R.E. Calcutta, 1906.

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Unclassified Papers.—(*Concluded*).

8. *The Simla Estates Boundary Survey on the scale of 50 feet to 1 inch, by Captain E. A. Tandy, R.E. Calcutta, 1906.

9. *A note on the stage reached by the Geodetic Operations of the Survey of India in 1920, by Lt.-Colonel H.McC. Cowie, R.E. The Magnetic Survey of India, by Major R. H. Thomas, D.S.O., R.E. and a note on the present levelling policy, by Major K. Mason, M.C., R.E. Dehra Dūn, 1922. (Out of print).

Geodesy.

1. Notes on the Theory of Errors of Observation, by J. Eccles, M.A. Dehra Dūn, 1903. *Price As. 8.*

2. *Note on a Change of the Axes of the Terrestrial Spheroid in relation to the Triangulation of the G.T. Survey of India, by J. de Graaff Hunter, M.A. Dehra Dūn. (Out of print), now incorporated in Professional Paper No. 16.

3. Report on the Treatment, and use of Invar in measuring Geodetic Bases, by Captain H. H. Turner, R.E. London, 1907. *Price As. 8.*

Projections.

1. On the projection used for the General Maps of India. Dehra Dūn, 1903.

2. *On the deformation resulting from the method of constructing the International Atlas of the World on the scale of one to one million, by Ch. Lallemand. Translated by J. Eccles, M.A., together with tables for the projection of 1/M Maps on the International system. Dehra Dūn, 1912.

Mapping.

1. *A Note on the different methods by which hills can be represented upon maps, by Colonel S. G. Burrard, C.S.I., R.E., F.R.S., Surveyor General of India. Simla, 1912.

2. *A Note on the representation of hills, by Major C. L. Robertson, C.M.G., R.E. Dehra Dūn, 1912.

3. *A Note on the representation of hills on the Maps of India, by Major F. W. Pirrie, I.A. Dehra Dūn, 1912.

4. *A consideration of the Contour intervals, and Colour Scales, best suited to Indian 1/M maps, by Captain M.O'C. Tandy, R.E. Calcutta, 1913. (Out of print).

Professional Papers.

No. 1. **Projection.** On the Projection for a Map of India, and adjacent Countries, on the scale of 1: 1,000,000, by Colonel St. G. C. Gore, R.E. Second Edition. Dehra Dūn, 1903. *Price Re. 1.*

No. 2. ***Base Lines.** Method of measuring Geodetic Bases by means of Metallic Wires, by M. Jäderin. (Translated from Memoires Prēsentēs par Divers. Savants ā l' Acadēmie des Sciences de l' Institute de France). Dehra Dūn, 1899. (Out of print).

No. 3. **Base Lines.** Method of measuring Geodetic Bases by means of Colby's Compensated Bars, compiled by Lieut. H. McC. Cowie, R.E., Dehra Dūn, 1900. (Out of print).

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Professional Papers.—(*Continued*).

No. 4. **Spirit levels.** Notes on the Calibration of Levels, by Lieut. E. A. Tandy, R.E. Dehra Dūn, 1900. (Out of print).

No. 5. **Geodesy.** The Attraction of the Himālaya Mountains upon the Plumb-Line in India, considerations of recent data, by Major S. G. Burrard, R.E. Second Edition, Dehra Dūn, 1901. *Price Rs. 2.*

No. 6. **Base Lines.** Account of a Determination of the Coefficients of Expansion of the Wires of the Jäderin Base Line Apparatus, by Captain G. P. Lenox-Conyngham, R.E. Dehra Dūn, 1902. *Price Re. 1.*

No. 7. ***Miscellaneous.** Calcutta, 1903. *Price Re. 1.*

(1) On the values of Longitude employed in maps of the Survey of India.

(2) Levelling across the Ganges at Dāmukdia.

(3) Experiment to test the increase in the length of a levelling staff due to moisture and temperature.

(4) Description of a Sun-dial designed for use with tide-gauges.

(5) Nickel-steel alloys and their application to Geodesy. (Translated from the French).

(6) Theory of electric projectors. (Translated from the French).

No. 8. **Magnetic.** Experiments made to determine the temperature coefficients of Watson's Magnetographs, by Captain H. A. Denholm Fraser, R.E. Calcutta, 1905. *Price Re. 1.*

No. 9. **Geodesy.** An Account of the Scientific work of the Survey of India, and a Comparison of its progress with that of Foreign Surveys. Prepared for the use of the Survey Committee assembled in 1905, by Lt.-Colonel S. G. Burrard, R.E., F.R.S. Calcutta, 1905. *Price Re. 1.*

No. 10. **Pendulums.** The Pendulum Operations in India, 1903-1907, by Major G. P. Lenox-Conyngham, R.E. Dehra Dūn, 1908. *Price Rs. 2-8.*

No. 11. **Refraction.** Observations of Atmospheric Refraction, 1905-09, by H. G. Shaw, Survey of India. Dehra Dūn, 1911. *Price Re. 1.*

No. 12. **Geodesy.** On the Origin of the Himālaya Mountains, by Colonel S. G. Burrard, C.S.I., R.E., F.R.S. Calcutta, 1912. *Price Re. 1.*

No. 13. **Isostasy.** Investigation of the Theory of Isostasy in India, by Major H. L. Crosthwait, R.E. Dehra Dūn, 1912. *Price Re. 1.*

No. 14. **Refraction.** Formulæ for Atmospheric Refraction, and their application to Terrestrial Refraction and Geodesy, by J. de Graaff Hunter, M.A. Dehra Dūn, 1913. *Price Rs. 2.*

No. 15. **Pendulums.** The Pendulum Operations in India and Burma, 1908-13, by Captain H. J. Couchman, R.E. Dehra Dūn, 1915. *Price Rs. 2-8.*

No. 16. **Geodesy.** The Earth's Axes and Triangulation, by J. de Graaff Hunter, M.A. Dehra Dūn, 1918. *Price Rs. 4.*

No. 17. **Isostasy.** Investigations of Isostasy in Himālayan and neighbouring regions by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. Dehra Dūn, 1918. *Price Re. 1.*

No. 18. **Isostasy.** A criticism of Mr. R. D. Oldham's memoir "The structure of the Himālayas and of the Gangetic Plain", by Lt.-Colonel H. McC. Cowie, R.E. Dehra Dūn, 1921. *Price Rs. 1-8.*

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Professional Papers.—(*Concluded*).

No. 19. **Aerial Photography.** Experiments in Aeroplane Photo Surveying, by Major C. G. Lewis, R.E., and Captain H. G. Salmond, (Late R.A.F.). Dehra Dūn, 1920. *Price Rs. 1-8.*

No. 20. **Air Survey.** Reconnaissance Survey from Aircraft, by Lt.-Colonel G. A. Beazeley, D.S.O., R.E. Dehra Dūn, 1927. *Price Rs. 1-8.*

No. 21. **Rectangulation.** Irrigation and Settlement Surveys 1926, by Major J. D. Campbell, D.S.O., R.E. Dehra Dūn 1927. *Price Rs. 1-8.*

No. 22. **Levelling.** Three Sources of Error in Precise Levelling, by Captain G. Bomford, R.E. Dehra Dūn, 1929. *Price Rs. 1-8.*

No. 23. * **Air Survey.** Air Survey of Wazīristān 1923 to 1928, by Captain G. F. Heaney, R.E. Dehra Dūn, 1928. *Price As. 8.*

No. 24. **Air Survey.** Notes on Air Survey in India, by Major W. J. Norman, M.C., R.E. Dehra Dūn, 1929. *Price Rs. 1-8.*

No. 25. **Glaciers.** The Representation of Glaciated Regions on maps of the Survey of India, by Major Kenneth Mason, M.C., R.E. Dehra Dūn, 1929. *Price As. 8.*

No. 26. **Geography.** Mount Everest and its Tibetan Names, by Colonel Sir S. G. Burrard, K.C.S.I., F.R.S. Dehra Dūn, 1931. *Price As. 8.*

No. 27. **Gravity.** Gravity Anomalies and the Structure of the Earth's Crust, by Major E. A Glennie, D.S.O., R.E. Dehra Dūn, 1932. *Price Rs. 1-8.*

Departmental Papers.†

No. 1. **Type.** A consideration of the most suitable forms of type for use on maps, by Captain M. O'C. Tandy, R.E. Dehra Dūn, 1913.

No. 2. **Symbols.** A review of the Boundary Symbols used on the maps of various countries, by Captain M.O'C. Tandy, R.E. Dehra Dūn, 1913.

No. 3. **Maps.** Extract from "The New Map of Italy, Scale 1: 100,000", by Luigi Giannitrapani. Translated from the Italian by Major W. M. Coldstream, R.E. Dehra Dūn, 1913.

No. 4. **Town Surveys.** A report on the practice of Town Surveys in the United Kingdom and its application to India, by Major C. L. Robertson, C.M.G., R.E. Dehra Dūn, 1913.

No. 5. **Stereo-plotter.** The Thompson Stereo-plotter and its use, with notes on the field work, by Lieut. K. Mason, R.E. Dehra Dūn, 1913.

No. 6. **Levelling.** Levelling of High Precision, by Ch. Lallemand. Translated from the French by J. de Graaff Hunter, M.A. Dehra Dūn, 1914.

No. 7. **Standard Bars.** Bar Comparisons of 1907-08, by Major H. McC. Cowie, R.E. Dehra Dūn, 1915.

No. 8. **Helio-Zincography.** Report on Rubber Off-set Flat bed Machine Printing, by Captain S. W. Sackville Hamilton, R.E. Calcutta, 1915.

No. 9. **Stereo-Auto-Plotting.** A translation of Paul Corbin's French Stéréo Autogrammétrie, by Lt.-Colonel H. McC. Cowie, R.E. Dehra Dūn, 1922.

No. 10. **Base Lines.** A Booklet of Instructions with full descriptions and tables for the Hunter Short Base, First Edition compiled by Major C. M. Thompson, I.A. Dehra Dūn, 1928. Second Edition Compiled by H. C. Banerjea, B.A. Dehra Dūn, 1931.

No. 11. **Gravity and Isostasy.** Investigations regarding Gravity and Isostasy by W. Heiskanen (Translated by V. Pelts Esq. Revised and completed by Major C. M. Thompson, I.A.) Dehra Dūn, 1928.

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Departmental Papers.*—(*Concluded*).

No. 12. **Geodesy.** Geodesy, by J. de Graaff Hunter, M.A., SC.D., F. INST.P. Dehra Dūn, 1929.

No. 13. **Spherical Trigonometry and Astronomy.** Notes on Spherical Trigonometry, and Astronomy etc., by Lt.-Colonel C. M. Thompson, I.A. Dehra Dūn, 1929.

No. 14. **Wild Theodolite.** Instructions for the use of the Wild Universal Theodolite by Captain D. R. Crone, R.E., and the Wild Photo-Theodolite by Lt.-Colonel C. G. Lewis, O.B.E., R.E. Dehra Dūn, 1932.

No. 15. **Air Survey.** Notes on Air Survey and Map Publication in England, 1931, by Major H. R. C. Meade, I.A., with a foreword by Captain D. R. Crone, R.E. Calcutta, 1932.

Professional Forms.

A large number of forms for the record and reduction of Survey Operations are stocked at Dehra Dūn.

List of more important contributions by the Officers of the Survey of India to various extra-departmental publications and related articles.

1. †India's Contribution to Geodesy, by General J. T. Walker, R.E., C.B., F.R.S., LL.D. (Philosophical Transactions, Royal Society, Series A, Volume 186, 1895).

2. †On the Intensity and Direction of the Force of Gravity in India, by Lt.-Colonel S. G. Burrard, R.E., F.R.S. (Philosophical Transactions, Royal Society, Series A, Volume 205, pages 289-318, 1905).

3. ‡A climb on Kolahoi, by Lieut. Kenneth Mason, R.E. (Royal Engineers Journal, November 1910).

4. †On the effect of the Gangetic Alluvium on the Plumb-line in Northern India, by R. D. Oldham, F.R.S. (Proceedings of the Royal Society, Series A, Volume 90, pages 32-40, 1914).

5. †On the origin of the Indo-Gangetic trough, commonly called the Himālayan Foredeep, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Proceedings of the Royal Society, Series A, Volume 91, pages 220-238, 1915).

6. §Three comprehensive articles on "Comparators for the Indian Government" from a report by Major H. McC. Cowie, R.E. (Engineering, Aug. 20, Aug. 27, Sept. 3, 1915).

7. ||Identification of Peaks in the Himālaya with notes, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Geographical Journal, September 1918).

8. ||Geological interpretations of Geodetic Results, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Geographical Journal, October 1918).

9. ||War Surveys in Mesopotamia, by Colonel F. W. Pirrie, C.M.G., I.A. (Geographical Journal, December 1918).

10. ||Air Photography in Archæology, by Lt.-Colonel G. A. Beazeley, D.S.O., R.E. (Geographical Journal, May 1919).

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

‡ Obtainable from the Institution of Royal Engineers, Chatham.

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27. §The Survey of Mr. W. H. Johnson in the K'un Lun in 1865, by Major K. Mason, M.C., R.E. (Alpine Journal, November 1922).

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29. *Trigonometrical Heights and Atmospheric Refraction, by J. de Graaff Hunter, M.A., SC.D., F.INST.P. (A Dictionary of Applied Physics, Vol. III).

30. Geodesy, by Colonel Sir G. P. Lenox-Conyngham, R.E., F.R.S. and J. de Graaff Hunter, M.A., SC.D., F.INST.P. (Enc. Brit. 12th Edition, Vol. XXXI, 1922).

31. †The proposed Determination of Primary Longitudes by International Co-operation, by Colonel Sir G. P. Lenox-Conyngham, R.E., F.R.S. (Geographical Journal, February 1923).

32. †Recent Developments of Air Photography. (1) The adjustment of Air Photographs to Survey points, by Lt.-Colonel M. N. MacLeod, D.S.O., R.E. (Geographical Journal, June 1923).

33. ‡Mount Everest, by Major H. T. Morshead, D.S.O., R.E. (Royal Engineers Journal, September 1923).

34. †Kishen Singh and the Indian Explorers, by Major K. Mason, M.C., R.E. (Geographical Journal, December 1923).

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37. †The Demarcation of the Turco-Persian Boundary in 1913-14, by Colonel C. H. D. Ryder, R.E. (Geographical Journal, September 1925).

38. Geodesy, by J. de Graaff Hunter, M.A., SC.D., F.INST.P. (Enc. Brit. 13th Edition, New Vol. ii, 1926).

39. **The De Filippi Expedition to the Eastern Kara-koram, by B.B.D. and Colonel Sir G. P. Lenox-Conyngham, R.E., F.R.S., M.A. (Nature, 13th February 1926).

40. †The Problem of the Shaksgam Valley, by Colonel Sir Francis Younghusband, K.C.S.I., K.C.I.E. (Geographical Journal, September 1926).

41. †The Shaksgam Valley and Aghil Range, by Major K. Mason, M.C., R.E. (Geographical Journal, April 1927).

42. A Break-Circuit for Pendulum Clocks, by J. de Graaff Hunter, M.A., SC.D., F.INST.P. (Bulletin Géodésique No. 14, April, May, June 1927, Paris).

43. †A Graphical Discussion of the Figure of the Earth, by A. R. Hinks, C.B.E., F.R.S. (Geographical Journal, June 1927).

44. ‡Survey on Active Service, by Captain G. F. Heaney, R.E. (Royal Engineers Journal, June 1927).

45. A Report on the Geodetic work of the Survey of India for the period 1924-27, by J. de Graaff Hunter, M.A., SC.D., F.INST.P., presented at the third meeting of the International Union of Geodesy and Geophysics, Prague, September 1927. Dehra Dūn, 1927. *Price Re. 1.*

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List of more important contributions by the Officers of the Survey of India &c. &c.—*(Continued)*.

46. *The Stereographic Survey of the Shaksgam, by Major K. Mason, M.C., R.E. (Geographical Journal, October 1927).

47. *Figure of the Earth: correspondence by J. de Graaff Hunter, M.A., SC.D., F.INST.P. (Geographical Journal, December 1927).

48. *Figure of the Earth: correspondence by Captain G. Bomford, R.E. (Geographical Journal, December 1927).

49. * Reply to Captain G. Bomford's letter on Figure of the Earth (No. 48 of list), by Captain G. T. McCaw and A. R. Hinks, C.B.E., F.R.S. (Geographical Journal, December 1927).

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51. * Note on Sir Francis Younghusband's Urdok Glacier, by Major Kenneth Mason, M.C., R.E. (Geographical Journal, March 1928).

52. † Some Applications of the Geoid by J. de Graaff Hunter, M.A., SC.D., F. INST.P. (The Observatory, June 1928).

53. ‡ The Attraction of the Himālaya, by J. de Graaff Hunter, M.A., SC.D., F.INST.P. (Himālayan Journal, Vol. I, No. 1, April 1929, pages 59 – 66).

54. * The Kara-koram: Correspondence regarding the proper nomenclature of the Kara-koram Himālaya, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S., Dr. T.G. Longstaff and Major Kenneth Mason, M.C, R.E. (Geographical Journal, September 1929 and January 1930).

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56. || The Glaciers of the Kara-koram and Neighbourhood, by Major Kenneth Mason, M.C., R.E. (Records of the Geological Survey of India, Volume LXIII, part 2, 1930, pages 214–278).

57. A Report on the Geodetic work of the Survey of India for the period 1927-30, by J. de Graaff Hunter, M.A., SC.D., F. INST. P., presented at the fourth meeting of the International Union of Geodesy and Geophysics, Stockholm, August 1930. Dehra Dūn, 1930. *Price Rs. 1-12.*

58. The Indian Geoid and Gravity Anomalies by J. de Graaff Hunter, M.A., SC.D., F. INST. P. and Captain G. Bomford, R.E. (Bulletin Géodésique, No. 29 Jan. – Mar. 1931, pages 20, 21, Paris).

59. Construction of the Geoid, by J. de Graaff Hunter, M.A., SC.D., F INST. P. and Captain G. Bomford, R.E. (Bulletin Géodésique, No. 29 Jan.—Mar. 1931, pages 22-26, Paris).

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|| Government of India Central Publication Branch, Calcutta.

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60. *Two Notes on Short Tertiary Bases, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Empire Survey Review No. 1, Vol. I, July 1931, pages 12-15).

61. †Contribution to discussion on paper by Mr. A. R. Hinks, C.B.E., F.R.S. "Some Problems of the Earth's Crust". British Association, 1931, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Geographical Journal, November 1931).

62. ‡, §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, Jan. 1932).

63. *Review of Captain Hotine's "Survey from the Air Photographs", by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Empire Survey Review No. 3, Vol. I, Jan. 1932, pages 134-137).

64 ||Stokes's Formula in Geodesy, by B. L. Gulatee, M.A. (Cantab) (Nature, 20th February 1932).

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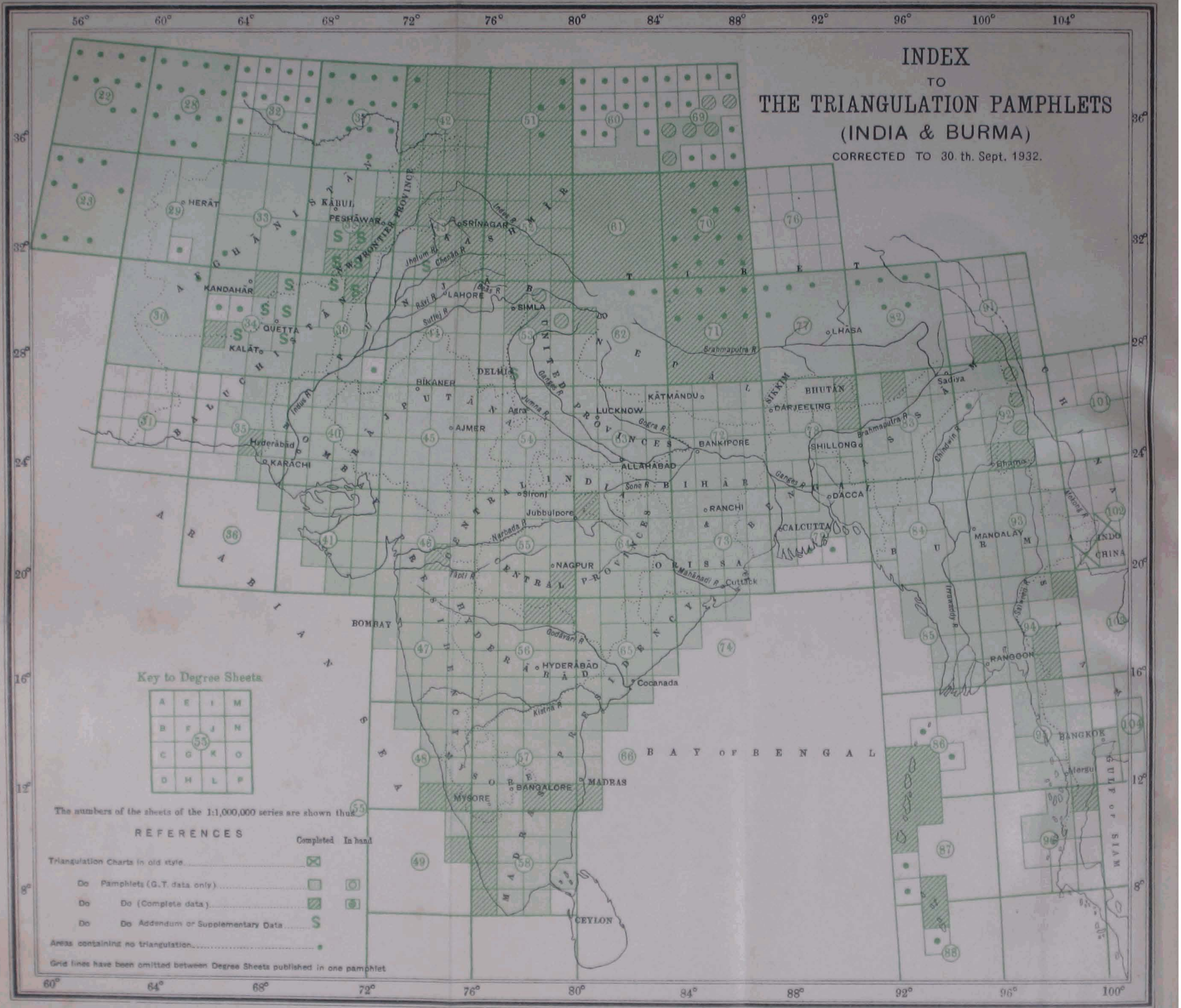
Chart XIX



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