Lieutenant I. M. Cadell R.E.
1902—1930.

LIEUTENANT IAN MACFARLANE CADELL, R. E.

Lieutenant Cadell, whose photograph appears as the frontispiece of this volume, joined the Survey of India in February 1926, having been commissioned in the Royal Engineers on August 31st 1922. He died at Loi Hkiao in the Southern Shan States on December 27th 1930, while engaged in principal triangulation.

In 1927 and 1928 he was employed on topographical work, principally on the survey of Chitrāl, a difficult country well-suited to his energetic character. From August 1929 until his death he was in charge of the primary triangulation party, and undertook the connection of the Indo-Burmese triangulation with that of Siam. After overcoming many difficulties during his first season in the Shān States, the work was progressing very well during the second season, and was nearly completed when he was attacked by pneumonia, of which he died a few days later.

Lieutenant Cadell was an officer of great energy and enthusiasm, who appeared to enjoy discomfort. It was characteristic of him that he should have ignored his attack of pneumonia until it was too late for assistance to be sent. By his untimely death the Survey of India, and his many friends, have suffered a great loss.

SURVEY OF INDIA

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INTRODUCTION

During the year 1930-31 the Geodetic Branch suffered the loss of one of its most devoted members. LIEUT. I.M. CADELL, R. E., was engaged on the triangulation in Burma which makes the first high-class connection of the great Indo-Burmese framework with the extensive geodetic triangulation of Siam and French Indo-China. After overcoming many difficulties he was within sight of the completion of the work. His zeal for this made him pay scant attention to his own well-being, and by the most cruel fortune he contracted pneumonia on one of the hill stations of the triangulation. His over-delayed appeal for medical help was too late and he died on 27th December 1930 at Loi Hkiao, Southern Shān States, before medical assistance could reach him. A photograph of Lieut. Cadell, who was held in high esteem by all his colleagues, who greatly deplore his loss, forms the frontispiece of this volume.

The usual activities of the Geodetic Branch were continued during 1930-31 both at Headquarters and in the field where gravity, latitude and longitude, triangulation and spirit-levelling observations were made.

Gravity and deflection work.—(Chapter IV Sec. II and Chapter V) Major E.A. Glennie, D.S.O., R.E., was in charge of the gravity work and operated mainly in the trackless and waterless Bīkaner Desert. In this region there are few natural features and the geographic positions of the stations were fixed by an accurate subtense traverse. A distance of about 150 miles was covered in this way by observations to a Hunter Short Base, the subtense distance averaging 1¾ miles. The closing error between two series of geodetic triangulation was 1/6,000 and geodetic positions may be considered good to one second of arc. Nine stations were observed at with the large prismatic astrolabe whereby deflections in both meridian and prime vertical were obtained and at six of these the value of *g* also was determined.

Observations were also made on this section of the work with a "Gravity Gradiometer". This is the first season that this instrument has been employed by the Survey of India and it is regrettable that instrumental faults were found to exist which rendered the results unreliable—particularly unfortunate as the great natural difficulties of the country had been successfully overcome.

The pendulum work was not confined to this area where about half the season was spent, and values of *g* were also determined at 16 other stations—in all 22. Major Glennie briefly reviews the results obtained.

A latitude detachment (Chapter IV Sec. I) under Mr. R.B. Mathur worked in another region along meridian 75°E. Forty-four stations at intervals of about 10 miles were distributed between Ajmer (lat. 26°) and Banihāl Pass (lat. 33° 30′). Observations were made by the Talcott method using the small Zenith Telescope. The special object of this work was to strengthen the connection of the geoid in Kashmīr with the rest of India. Captain G. Bomford, R.E. discusses the results in Chapter IV Sec. I. Reference to G. R. Vol. III may be made, where certain conjectures as to the geoidal form in the region now explored were made. These have been justified by the results of the past season and we now have reliable geoidal results for the first serious penetration of the Himālaya. The superiority of Survey of India spheroid II over the International spheroid in fitting the geoid *in India* is also conspicuous. The notable difference of this spheroid is in the flattening: the elements of the two spheroids being—

	Semi-axis major	Flattening
Survey of India, II ...	6,378,541 metres	1/292·4
International ...	6,378,388 metres	1/297

The latitude observer Mr. R.B. Mathur is to be congratulated on the successful completion of this programme. The 44 stations were in 32 cases at or near old stations of triangulation but the positions of the residue had to be fixed by resection. This is the first occasion on which the recently adopted principle (*vide* Chapter IV Sec. I paras 2 and 4) of measuring deflections with somewhat reduced precision, but at closer intervals (10 miles) than was done formerly, has been adopted. The deflection stations cannot in all cases be located at, or adjacent to the triangulated stations and recourse has to be made to resection to fix their geodetic positions. The result is a much more detailed and accurate knowledge of the geoidal form, which is essential for the continued development of the study of the earth's crust by the powerful geoidal methods introduced in India during the last ten years. It is hoped to apply the same method to longitude as well as latitude deflections, and observations of deflections on a line across India via Calcutta, Benares and Jhānsi are in the programme for field season 1932-33.

Isostasy denied.—I have been at some pains, especially during the last year, to point out that the Hayford hypothesis of isostasy does not fit the facts of continental India (*vide* Nature April 18th, 1931 pp. 593-594; Empire Surveyors Conference 1931; British Association 1931, discussion of Mr. Hinks paper "Problems of the

Earth's Crust" reprinted in the Geographical Journal Nov. 1931; Geophysical Supplement to R.A.S. M.N., Jan. 1932). Such extravagant claims have been made for the universality of isostasy, that it has been deemed imperative to reiterate that the evidence of the extensive Indian results is in strong contradiction. I have dealt with the negation of isostasy as shown by the deflection and g–anomalies. Major Glennie (Chapter V § 6) has considered the physico-geological case and concludes that topographical and abnormal crustal densities are not compensated: and that deep-seated departures from normal density arise from depressions or elevations of the denser layers of the crust. His argument, only briefly summarized in Chapter V, is set forth fully in Professional Paper No. 27 "Gravity Anomalies and the Structure of the Earth's crust", just published.

Triangulations and Bases.—(Chapter VI). In the season 1930-31 two connections were made between the Burmese geodetic triangulation and that of Siam, one at latitude 20° and other at latitude 11°. These connections are of primary importance to geodesy. The field for possible study of the geoid is increased by the whole of the Siamese and French Indo-China areas: and it is to be also remembered that the connection of the Siam triangulation with that of Malay is already begun. It is to be hoped that the necessary deflection observations in these various regions will soon be taken up. To control the 20° connection a precise base-line was measured at Kengtung, in the neighbourhood of the former junction, as well as necessary deflections of the plumb-line: and in the season 1932-33 a Laplace point will be formed there. The triangulation proper was nearly finished by Lieut. Cadell. After his death the remaining figures of the triangulation, the base and the deflections were observed by Capt. Bomford. In regions where the deflections of the plumb-line exist a correction is required to the horizontal angles measured with a theodolite but this correction is negligible when the observed rays are very nearly horizontal or where the deflection is trifling. When, however, rays of considerable elevation, such as 5°, are associated with deflections amounting to 30″ the correction may be as much as 3″ (see Chapter VI § 5). I drew attention to this in 1918 (Professional Paper No. 16 p. 77). Now it is likely to happen that the rays connecting a base-line with triangulation are considerably elevated: for in hilly country, convenient for triangulation, the base is naturally located in a valley or small plain. Considerable deflections are in this case likely, the more so if the locality is remote from the origin of survey. In such cases it is essential that the deflections be measured, so that the corrections to angles of triangulation may be applied: failing which all the precision of the base is liable to be thrown away in the connecting triangles and never reaches the main triangulation. Accordingly at Kengtung the deflections in both components of all the stations of the base-line figure have been observed—probably the first time on which this necessary procedure has been followed.

As regards the azimuth observations a departure from the old practice in the Survey of India was made. Instead of observing to close circum-polar stars near elongation it is intended in future to observe Polaris *at any hour angle.* This was done at the Kengtung stations.

In view of the fact that the nearest Laplace point is 300 miles distant, considerable accumulation of triangulated azimuth (*probable* value about 3″) is sure to have occurred. Full use of the deflections can only be made after this accumulated error has been assessed by the formation of a Laplace point at Kengtung. This is in the programme for 1932-33.

The triangulation near latitude 20° completed this season, apart from its importance as a junction with the triangulation system of Siam and French Indo-China (*vide* Chart I), also connected the Mong Hsat and Great Salween series, thereby greatly strengthening the Burma Quadrilateral. With the measurement of bases at Akyab and Moulmein (in programme for 1932-33) this Quadrilateral will have nearly approached completion and its partial re-adjustment (not necessarily in full detail) could properly be taken up. The closure of all this work is quite satisfactory.

The other triangulation at latitude 11° will greatly strengthen the Burma Coast series—a pendant series. A larger discrepancy in log side found on junction with the Siamese work cannot as yet be satisfactorily accounted for, but perhaps the re-measurement of the short Mergui Base (in programme for 1932-33) will localize the error. The question of these closing errors is considered in Chapter I, § 1.

It has always been a matter of great interest to the Survey of India that its triangulation should be linked with that of Europe. In 1913 a junction was made with the Russian triangulation in the Pāmirs and it was hoped that in due course the Russian triangulation would be connected with Europe. Since that time, however, it has been difficult to ascertain to what extent, if any, this hope had become realized. Recently a Russian publication has been received from the Institute of Geodesy and Cartography, Moscow, in which is a summary of the triangulation effected in Turkistan. This unfortunately shows conclusively that no geodetic connection can be hoped for in that direction for many years. The position is explained in Chapter I § 4.

The measurement of a base at Kengtung required a considerable amount of preliminary work. The last occasion on which a geodetic base was measured in India was in 1882 at Mergui by means of the old Colby Bar apparatus. The need for further bases, as the triangulation of India and Burma expanded was felt in the early part of this century, and a very fine equipment with new standards of length, comparators for bars and tapes was acquired in 1913.

Progress with base-lines was, however, entirely impeded by the Great War and the staff of the Geodetic Branch were able to do no more in this work than erect the apparatus and bring it approximately into a state fit for use. In anticipation of the Kengtung Base, comparisons of the various field wires and the standards were carried out by Capt. Bomford. These are dealt with in Chapter II § 1. An unexpected change in the relative lengths of the silica and nickel metre bars, since 1914, amounting to 5μ has been brought to light, which re-standardization at the National Physical Laboratory in 1931 has shown to be due to a change in the nickel standard.

Generation of error in triangulation.—A paper on The Lay-out of Geodetic Triangulation read at the Conference of Empire Surveyors in London, 1931 is reprinted by permission in Chapter IX. It is hoped that this will be a useful guide.

Longitude.—(Chapter II § 2). A Shortt clock has been erected and started. Regular observations of longitude at Dehra Dūn have been continued throughout the year.

Latitude variation.—Has also been regularly observed with satisfactory results. (Chapter II § 3).

The *Tidal work* is dealt with in Chapter III.

Magnetic work.—(Chapter VIII). A magnetic survey of India and Burma was completed during the period 1901-1920 based on magnetic observatories at Dehra Dūn (1902), Barrackpore (1903) near Calcutta, Alībāg (Bombay), Kodaikānal (1902), Toungoo (1904), and 1425 field stations which included 80 repeat stations. The original plan was that the survey should be kept up to date by the maintenance of some of these observatories and re-observation at intervals of 5 years at the 80 repeat stations. Economic conditions have prevented the fulfilment of this intention. The observatories at Dehra Dūn and Alībāg have been maintained in continued operation: others were closed down as follows:—

Barrackpore ...	... (April 1915)
Kodaikānal ...	... (Oct. 1923)
Toungoo ...	... (Oct. 1923)

As regards the repeat stations, since 1920 only 6 were re-observed in 1921-22 and 7 in 1922-23. As a result the amount of secular changes, except in the vicinity of Dehra Dūn and Alībāg, had become unknown and it was impossible to reduce results of the Magnetic Survey to an epoch as late as 1930.

It was decided then to revisit all the repeat stations and to reopen the observatories at Kodaikānal and Toungoo. As a start 37 repeat stations in the area which was deemed to be adequately supported by the observatories at Dehra and Alībāg were re-occupied in 1930-31. The observations have been reduced to epoch 1931·0.

It is regrettable that the present financial situation has negatived the considerable cost of reopening the Kodaikānal and Toungoo observatories as planned; without which field observations at the remaining repeat stations of SE. India and Burma could not be reduced. Accordingly no more field magnetic work will be carried out for the present.

Precision levelling.—(Chapter VII). Levelling of High Precision has been carried out by three detachments whereby a total equivalent length of 584 miles in both directions has been added to the level net. The total of this net so far accomplished now amounts to 8783 miles. The levelling in Burma is of the old class of "Levelling of Precision". It has been extended by the line Taunggyi-Kengtung with a view to fixing the height of the Kengtung Base measured this year as well as to correct heights of the Mong Hsat triangulation series. A further extension of this line is projected for 1932-33 to effect a junction with the precise levelling system of Siam.

The *personnel* of the Geodetic Branch during the year is given on the following pages.

DEHRA DŪN,
April 1932.

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

PERSONNEL* OF THE GEODETIC BRANCH, 1930-31.

Director, Geodetic Branch

Dr. J. de Graaff Hunter, m.a., sc. d., f. inst. p., to 18th April 1931

Lt.-Colonel F.J.M. King, r.e., from 19th April 1931

COMPUTING AND TIDAL PARTY

(Records and Research)

Class I Officers

Captain G. Bomford, r.e. in charge, to 3rd Jan. 1931 and from 24th Mar. 1931.

Dr. J. de Graaff Hunter, m.a., sc.d., f. inst. p., in charge from 4th Jan. 1931 to 23rd Mar. 1931.

Mr. B. L. Gulatee, m.a. (Cantab.), Asstt. Mathematical Adviser, from 21st Apr. 1931.

Class II Officers

Mr. M. N. A. Hashmie, b.a., from 13th Apr. 1931.

Computing Section

Upper Subordinate Service

Mr. R. C. Ray.
Mr. M. Chatterji.
Mr. S. Mitra.
Mr. H. C. Deva, b.a., from 1st Jan. 1931.
Mr. T. N. Sharma, b.a.
Mr. A. K. Maitra, b.a.
Mr. R. K. Bhattacharya, b.a.
Mr. Sayed Irshad Ahmad, b.a.
Mr. C. B. Madan, b.a.
Mr. M. Das Gupta, b.sc., (on probation) from 17th Nov. 1930.

Lower Subordinate Service

9 Computers.

Tidal Section

Class II Officers

Mr. D. H. Luxa, Tidal Assistant, to 16th Mar. 1931

Mr. R. B. Mathur, b.a., Tidal Assistant from 17th Mar 1931.

Lower Subordinate Service

12 Computers.

Observatory Section

Upper Subordinate Service

Mr. H. C. Banerjea, b.a.
Mr. G. P. Rao, m.a. (on probation).

Lower Subordinate Service

7 Computers.

Magnetic Observatory

Mr. K. N. Mukerji, m.a., to 11th Aug. 1931.

Mr. Shyam Narain, b.sc., from 8th Apr. 1931.

1 Computer.

Office and P. & M. Section

Upper Subordinate Service

Mr. B. B. Lal.

Lower Subordinate Service

1 Librarian.
2 Clerks.

Drawing Section

(Administered by O.C. 2 D.O.)

Upper Subordinate Service

Mr. L. D. Joshi, to 6th Oct. 1930 and from 20th Jan. 1931.

Lower Subordinate Service

8 Draftsmen.

Latitude Detachment

Class II Officers

Mr. R. B. Mathur, b.a., in charge, to 16th Mar. 1931.

Lower Subordinate Service

1 Computer.

Magnetic Detachment

Mr. Shyam Narain, b.sc., in charge to 7th Apr. 1931.

Lower Subordinate Service

1 Computer.

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* Excluding No. 2 Drawing Office, Publication & Stores and Forest Map Office

14 PARTY (PENDULUM)

Class I Officers

Major E. A. Glennie, D.S.O., R.E., in charge.

Upper Subordinate Service

Mr. L. D. Joshi, from 7th Oct. 1930 to 19th Jan. 1931.

Lower Subordinate Service.

3 Computers &c.

15 PARTY (TRIANGULATION)

Class I Officers

Lieut. I. M. Cadell, R.E., in charge, to 27th Dec. 1931.

Captain G. Bomford, R.E., in charge, from 4th Jan. 1931.

Class II Officers

Mr. M. N. A. Hashmie, B.A., to 12th Apr. 1931.

Upper Subordinate Service

Mr. P. K. Chowdhury.

Mr. L. R. Howard.

Mr. Khushal Khan, from 27th Aug. 1931.

Lower Subordinate Service

4 Computers &c.

17 PARTY (LEVELLING)

Class I Officers

Mr. H. P. D. Morton, in charge. to 7th Mar. 1931.

Class II Officers

Mr. D. H. Luxa, in charge from 9th Mar. 1931.

Upper Subordinate Service

Mr. P. B. Roy.

Mr. A. A. S. Matlub Ahmad.

Upper Subordinate Service—(Contd).

Mr. J. N. Kohli.

Mr. B. P. Rundev.

Mr. Mohd. Faizul Hasan.

Mr. I. D. Suri.

Lower Subordinate Service

31 Clerks, Computers, and Recorders, &c.

TRAINING SCHOOL

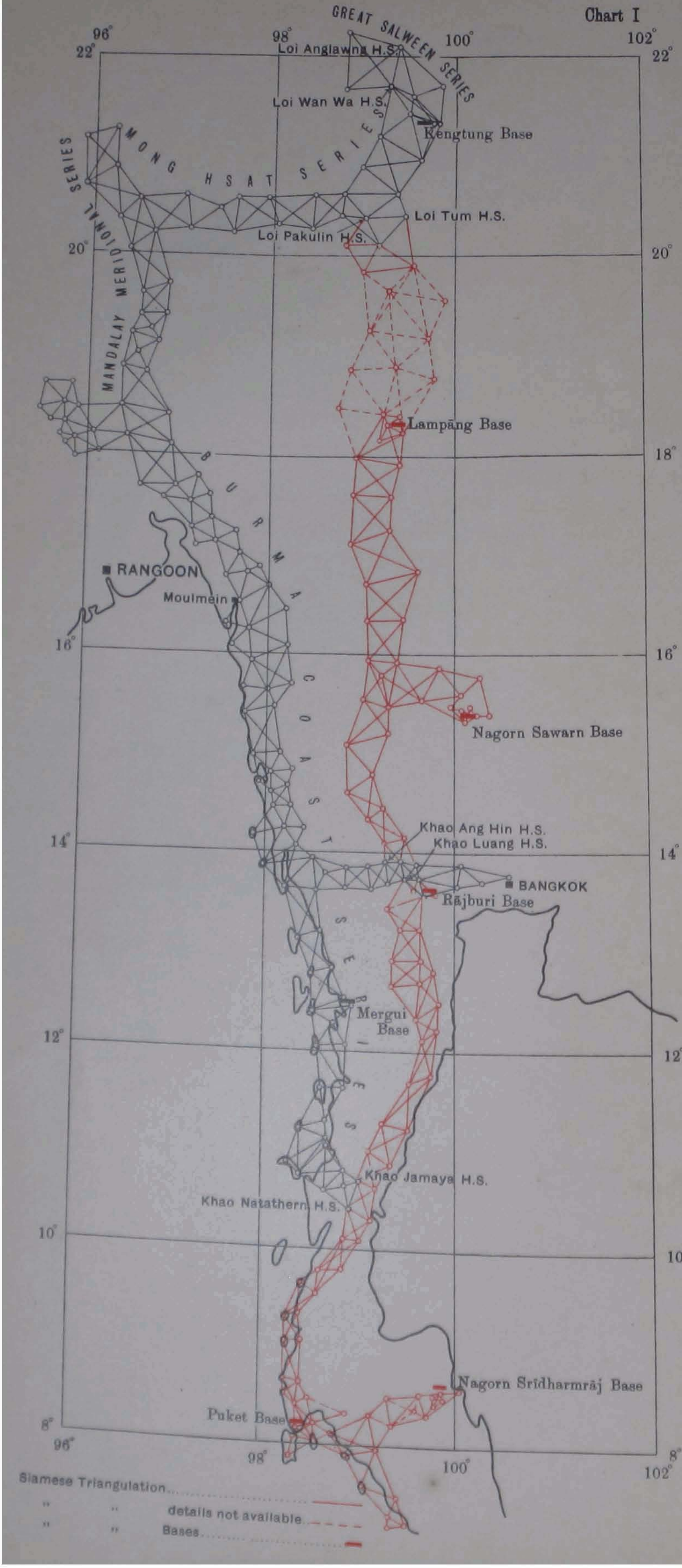
Mr. L. Williams, M.B.E., Survey Instructor, to 25th Dec. 1930.

Mr. M. M. Mudalier, M.A., Survey Instructor, from 26th Dec. 1930.

INDO-SIAMESE CONNECTIONS

Scale $\frac{1}{8,000,000}$ or 1·014 inches to 128 Miles.

Chart I



CHAPTER I

COMPUTATIONS AND PUBLICATION OF DATA

BY CAPTAIN G. BOMFORD, R.E.

1. Junction with Siamese Triangulation.—The only connection between the Siamese and Indian triangulation systems has hitherto been through the Bangkok Secondary Series in latitude 14° N., almost the least accurate of the series contained in the Indian geodetic triangulation. During the last year two other connections have been completed: one with the Mong Hsat and Great Salween Series in latitude 20°, and one with the southern end of the Burma Coast Series in latitude 10° (see Chart I). Table 1 (page 5) shows the discrepancies of latitude, longitude, log side, azimuth and height at these junctions. The last season's field work is described in Chapter VI of this report.

As regards latitude and longitude, the basis of the Siamese triangulation is the latitude and longitude of the Survey of India station Khao Luang, which were accepted by the Siamese Survey. In 1916 the Survey of India made a preliminary adjustment of their Burma triangulation, which changed the co-ordinates of all Burmese stations, so that the Siamese and Indian positions for Khao Luang H.S. are no longer identical. As regards log side and azimuth the Siamese Survey is independent of the Indian Survey. The Siamese have measured several bases of their own which have of course been utilized in their computations, and for fundamental azimuth they have accepted an astronomical azimuth observed near their Rājburi Base (latitude 13½°N.). Their computations are based on Everest's spheroid, as regards the axes of their spheroid, but, having adopted an independent fundamental azimuth, they cannot be said to be on the Survey of India Everest spheroid, and the two surveys are really in completely independent terms.

The Survey of India figures given in Table 1 are those now accepted and published in the triangulation pamphlets. They are the result of the preliminary adjustment made in 1916, which ignored all Laplace stations (Chittagong, Akyab, Prome and Moulmein) and also the Mergui Base. The figures given for the Mong Hsat Series ignore the recently completed connection with the Great Salween Series and the new Kengtung Base (see Table 2, page 5).

The discrepancies of azimuth and log side, shown in Table 1, are very considerable. The former are easily explainable, but the latter are not, and field work will be required in order to locate and remedy the error.

As regards azimuth, the Laplace stations at Prome and Moulmein indicate that the azimuths in the southern part of the Burma Coast Series require a correction of about $-11''$, and the Laplace station which it is proposed to form at Kengtung will probably show that the Mong Hsat Series requires a similar correction. To this extent the Indian azimuths are in error, and when the Burmese triangulation is completed and re-adjusted the error will be remedied. A further source of discrepancy lies in the Siamese Survey having assumed their geodetic azimuth to be equal to the astronomical when deciding on their fundamental azimuth*. The Siamese triangulation cannot be placed on the Indian Everest spheroid until a Siamese Laplace station is available to indicate the deflection of the plumb-line at their origin, but it is possible to estimate the magnitude of the discrepancy arising from this cause. If it can be assumed that the International spheroid accurately represents the geoid (which it certainly does much better than Everest's spheroid), the deflection anywhere in the Siamese triangulation will be about $14''$ east, and their astronomical and geodetic azimuths, instead of being in good agreement as at present, should differ by about $14'' \tan \phi$. The International spheroid is not, of course, sufficiently perfect for this prediction to be at all accurate, but we may expect to find that in order to express the present Siamese azimuths in Indian terms, corrections of about $14'' \tan\phi$ are necessary. Combining this correction with the known azimuth errors of the Indian geodetic azimuths, the expected discrepancies in latitudes 20°, 14° and 10° are $16''$, $14\frac{1}{2}''$ and $13\frac{1}{2}''$ respectively, leaving outstanding discrepancies (Survey of India *minus* Siamese) of $+1\frac{1}{2}''$, $+14''$ and $+1''$. Of these, the first and last are very satisfactory, even fortunate. The second is large, but to a great extent it can be fairly attributed to the low quality of the Bangkok Secondary Series.

The discrepancies in log side on the other hand, cannot be explained away. At the Mong Hsat junction (lat. 20°) the agreement is satisfactory: at the Bangkok junction it is very bad, although if it stood by itself the quality of the Bangkok Series could be held responsible: but the discrepancy of about 1: 10,000 at the south end of the Burma Coast Series (lat. 10°) can only be attributed to serious accumulation of error in one of the principal series of either the Indian or Siamese systems.

The figures given in Table 1 require some small modification before further consideration. The Siamese bases have been reduced to sea-level by means of their geoidal heights, while the Indian Everest spheroid lies about 200 feet below the geoid in this area (see Chapter VI, para 6). In order to express the Siamese triangulation in terms of this spheroid, it would therefore be necessary to reduce their sides by 200 feet in 4000 miles or 0·0000041 in the log. Indian

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* It is not suggested that the Siamese Survey were unwise to make this assumption. At this distance from the origin the Indian Everest spheroid is not at all a convenient reference figure.

sides are expressed in terms of Indian feet or tenths of standard Bar A (see Supplement to Geodetic Report Vol. VI, page vi). To bring the Siamese bases to the same terms requires an addition of 0·0000019 to the log. The total change in the Siamese log sides is thus −0·0000022, and the discrepancies in the last column of Table 1 require an addition of +0·0000022, and become +0·0000099, −0·0000455, and −0·0000454 at the three junctions.

In terms of the Great Salween Series the discrepancy at the lat. 20° junction is −0·0000044, while in terms of the newly measured Kengtung Base it is +0·0000027. This is satisfactory.

At the other two junctions the log side has been brought all the way from the Calcutta and Sonākhoda bases in Bengal, a distance of over 1000 miles. In triangulation of the best quality such an error as 0·0000480 is not to be expected, even after 1000 miles, but between latitudes 14½° and 16° there is a very weak part of the Burma Coast Series in which the side closures of four successive figures are 139, 55, 254 and 114 in the 7th decimal of the log. In this section there is clearly a possibility of some considerable proportion of the 480 discrepancy having accumulated. There is, however, the Mergui Base, which was ignored in the Burma adjustment. This base was measured in 1882 on the same system and with the same care as the other Indian bases, except that it was measured in one direction only and that it is shorter than is usual (3 miles). The discrepancy between the measured and the triangulated values of the base was 0·0000084, in such a sense that its acceptance would reduce the Indo-Siamese discrepancies to 0·0000371 and 0·0000370.

If this Mergui Base can be relied on, it is almost impossible that the Survey of India log side in latitude 10° could be in error by 0·0000370: an error of one third as much would be unlikely. South of Mergui the series consists of 5 simple triangles with average triangular errors of 0″·72 (worst 2″·07), and four other figures with average side closures of 0·0000023 (worst 59). In lat. 14°, as stated above, the Bangkok Series is capable of accumulating the whole 480 error itself: the side closures of the four figures west of Khao Luang average 185 in the 7th decimal (worst 471).

As regards the possibility of error in the Siamese triangulation, it must be remembered that this southerly section is probably the weakest part of the Siamese triangulation, since the nature of the country has enforced the use of rather elongated figures. The original closing error of log side between the Srīdharmrāj (lat. 8½° N.) and Rājburi bases (lat. 13½° N.) was only 0·0000141, but recent re-measurement of the Srīdharmrāj Base increased this figure to 0·0000248. In the nine figures between the Rājburi Base and the lat. 10° junction, the average log side closure has been 99 in the 7th decimal (worst 280). There thus seems to be a possibility that a considerable part of this lat. 10° discrepancy may lie in the Siamese series, although this cannot be considered to be at all certain.

The discrepancies of latitude and longitude call for little comment. The relative discrepancies at the lat. 20° and lat. 10° junctions are such as would naturally arise from the differences of azimuth and log side already discussed.

The discrepancies in height are not serious. The figures given are those brought up by the triangulation. In the case of the latitude 20° junction, a spirit-levelled connection at the Kengtung Base has shown that Survey of India heights require no correction. At the latitude 10° junction Survey of India heights are rather far removed from spirit-levelling, the nearest connection being at Moulmein where a reduction of 5 feet is indicated, which reduces the discrepancy to 6 feet. At this point the Siamese triangulation is closely connected to sea-level and its height is probably correct.

For some time it has been the intention of the Survey of India to measure bases at Akyab and Moulmein, and the re-measurement of the Mergui Base has now been added to the programme. The Siamese Survey also intend to make some additional observations in the weaker parts of their series, and to include a new base between Srīdharmrāj and Rājburi. These projects should serve to locate the weakness and probably to remedy it.

2. Mong Hsat—Great Salween Series junction.—The last two seasons' work of No. 15 Party, referred to in para 1, completes a circuit of triangulation in Burma. Details of the closing error are given in Table 2. The length of the circuit is 900 miles, so that the closing error of position (about 30 feet) represents an error of 1 : 160,000, which is satisfactory. Details of the closure of the other Indian circuits are given in Professional Paper No. 16, Table LIII.

The part of the Mandalay Meridional Series which enters into this circuit has already received some adjustment in the provisional adjustment of the Burma triangulation made in 1916. The closing errors given in Table 2 are consequently not exactly those which will enter into the final adjustment.

3. Chittagong Series.—The Chittagong Series, observed in 1928-30 has been adjusted between its terminal sides. This adjustment is of course provisional pending the final re-adjustment of all the Burmese triangulation. The closing errors adjusted are shown in Table 3, page 6. This series cuts in half one of the circuits already provisionally adjusted (1916). The length of each of the smaller circuits now formed is about 570 miles, in which the common closing error of 32 feet represents an error of 1 : 95,000.

TABLE 1.—*Discrepancies between Indian and Siamese Triangulation.*

Series	Station		Survey of India	Siamese	Survey of India *minus* Siamese
Mong Hsat (lat. 20°) (1929-31)	Loi Pakulin H.S.	Latitude	20° 20′ 37″·13	20° 20′ 39″·34	− 2″·21
		Longitude	99 00 26 ·12	99 00 25 ·82	+ 0″·30
		Height (ft.)	5170	5173	− 3
		Log side to Loi Tum	5·1859903	5·1859826	+ 0·0000077
		Azimuth of T at P	263° 06′ 33″·2	263° 06′ 15″·4	+ 17″·8
Bangkok Secondary (lat. 14°) (1878-81)	Khao Luang H.S.	Latitude	13° 43′ 28″·69	13° 43′ 30″·34	− 1″·65
		Longitude	99 32 21 ·52	99 32 22 ·94	− 1″·42
		Height (ft.)	1393	1383	+ 10
		Log side to Khao Ang Hin	5·0051230	5·0051707	−0·0000477
		Azimuth of L at A	311° 33′ 52″·2	311° 33′ 23″·4	+ 28″·8
Burma Coast (lat 10°) (1930-31)	Khao Jamaya H.S.	Latitude	10° 40′ 16″·50	10° 40′ 17″·10	− 0″·60
		Longitude	99 01 10 ·50	99 01 12 ·12	− 1″·62
		Height (ft.)	1828	1817	+ 11
		Log side to Khao Natathern	5·0000805	5·0001281	−0·0000476
		Azimuth of N at J	10° 08′ 52″·7	10° 08′ 38″·4	+ 14″·3

TABLE 2.—*Discrepancies between Mong Hsat & Great Salween Series.*

	(a) In terms of Great Salween 1900-1911	(b) In terms of Mong Hsat and Great Salween 1929-31	(a − b)
Latitude of Loi Wan Wa H.S. ...	21° 42′ 29″·96	21° 42′ 30″·24	− 0″·28
Longitude of Loi Wan Wa H.S.	99 18 17 ·61	99 18 17 ·81	− 0″·20
Height of Loi Wan Wa (feet) ...	6504	6514	− 10
Log side Loi Wan Wa—Loi Anglawng ...	5·1638714	5·1638857	−0·0000143
Azimuth of Loi Anglawng at Loi Wan Wa ...	188° 20′ 02″·7	188° 20′ 02″·0	+ 0″·7

In terms of the Kengtung Base, log side Loi Wan Wa—Loi Anglawng is 5·1638785.

In terms of the spirit-levelling to Kengtung the height of Loi Wan Wa is 6515.

TABLE 3.—*Closing errors of Chittagong Series.*

	(a) In terms of Burma Coast Series 1864-82	(b) In terms of Chittagong Series 1928-30	(a−b)
Latitude of Sitapahār H.S. ...	22° 29′ 28″·17	22° 29′ 28″·30	− 0″·13
Longitude of Sitapahār H.S. ...	92 10 03 ·50	92 10 03 ·81	− 0″·31
Height of Sitapahār (feet) ...	1135	1126	+ 9
Log side Sitapahār-Gilachhari .	4·8300369	4·8300249	+0·0000120
Azimuth of Gilachhari at Sitapahār	305° 00′ 26″·5	305° 00′ 24″·8	+ 1″·7

4. **Indo-Russian Triangulation junction.**—In 1913 a junction was made between the triangulation of India and Russia at Sarblock in the Pāmirs*. At the time when this work was undertaken it was hoped that its result would be the connection of the Indian and European triangulation systems, but it was soon discovered that this was not the case, and that the Russian work in Turkistan was still unconnected with Europe. No precise information was then available regarding the extent or quality of the Turkistan triangulation, and no further information was obtainable during and after the war, although in recent years rumours had reached India that triangulation of some sort was in progress. Recently, however, there has come into being an "Institute of Geodesy and Cartography" at Moscow, which publishes a periodical (in Russian) called the "Geodesist". In the April 1930 number of this periodical is a description† of all the triangulation hitherto carried out in Turkistan.

This article contains much of the information which has so long been sought, but it shows that hopes of a geodetic connection between India and Europe in this direction are quite unfounded. The work has not yet been begun.

Chart II, which is based on an illustration in the "Geodesist", shows all triangulation in Turkistan observed or projected up to 1929. The work is divided into three groups.

(*a*) 1871-1895. This is rapid exploratory work of which the article says:—"During this first period triangulation was of a haphazard nature, as it was carried out (usually at a rush) to meet the problems of the local commander. Owing to this it was difficult to have a real programme and a proper sequence of work, or to work on a strictly scientific basis. Therefore the connection between separate areas was incomplete or doubtful and shaky, or at times non-existent, and errors increased owing to the short life of the wooden centres or the complete absence of these. It must also be added that at times the limitations

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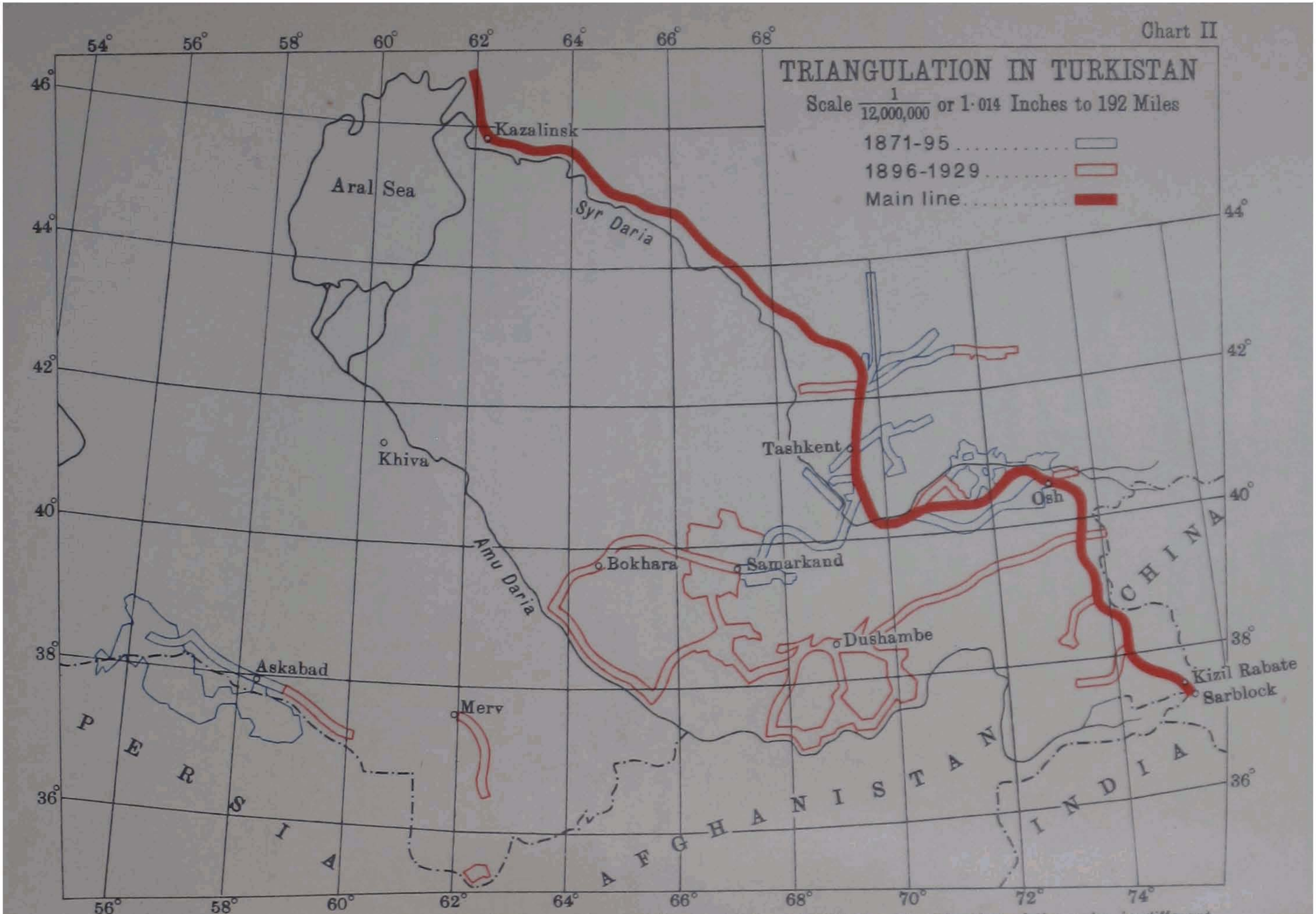
* See Survey of India Records Volume VI.

† This has been translated into English by Captain F.H. Gleeson, R.A.

Chart II

TRIANGULATION IN TURKISTAN

Scale $\frac{1}{12,000,000}$ or 1·014 Inches to 192 Miles



Note:— This chart is taken from page 23 of the Russian publication "Geodesist No. 4 1930" The identification of the series in different years, has been done in India, from the letter-press and some inaccuracy is possible.

of the problem, or special urgency, dictated the most speedy and simplified methods of triangulation, quite impermissible under normal circumstances ".

(*b*) 1895-1929 [excluding (*c*)]. This is probably ordinary topographical triangulation. No information is given regarding its quality, except that it is considered subsidiary to (*c*), below. Much of it has recently been recomputed and brought into common terms with (*c*).

(*c*) The "Main Turkistan Line", running from north of Kazalinsk near the Sea of Aral, through Tashkent to the Indo-Russian junction in the Pāmirs. This is clearly considered to be the most reliable series, but no information is given by which its quality can be judged. It is, however, known * that the accumulation of scale error between the bases at Osh and Kizil Rabate amounts to 1: 2700, a figure 30 or 40 times greater than is typical of geodetic triangulation. It is of course possible that the rest of the line is of better quality, having presumably been carried out under easier conditions, but the section Osh-Pāmir is referred to as part of the main chain, and no mention is made of its inferior quality.

It is thus practically certain that no Russian geodetic † triangulation exists in Turkistan. Nor can it even be said that geodetic triangulation has been carried up to the Indian frontier. The difficulties of the country are such that both the lay-out of the figures and the precision of angular measurement necessarily fall far short of geodetic standards. North of Hunza the side closures of successive figures average 0·0000364 (worst 982), and the closing error on the Russian base at Kizil Rabate is 1 : 4700 (930 in the 7th decimal of the log).

The probability of the Russian surveyors reobserving their "Main Turkistan Line" or of the Survey of India being able to improve on their connecting series, must be considered extremely remote, and the most hopeful direction for an Indo-European geodetic connection is probably through Persia and Asia Minor. Political and financial conditions are such as to offer no hope of the work being begun at present, but false hopes of an easy connection through Russia should not be allowed to distract attention from the necessity for it, if conditions should ever become more favourable.

5. Adjustment of minor triangulation.—The rough adjustment of topographical triangulation on the North-West Frontier, which was begun in 1926 (see Geodetic Report, Vol III, page 31)

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* Records Volume VI, page 116B.

† By the adjective "geodetic" is here implied triangulation of such quality as could contribute to the determination of the Earth's figure. The existing work is no doubt thoroughly adequate for the control of the topographical surveys which are based on it.

has been taken up again. In 1926 the confusion of the old records in 1/M sheets 34 & 39 was such that no progress could be made, but the confusion has now been straightened out, and the work is progressing well.

Adjustment of triangulation in N.W. Persia observed in 1917-19 has been carried out in a similar way, and also of triangulation observed in S.W. Persia in 1910-25 of which most has been observed for the Anglo-Persian Oil Company.

6. Computation forms.—Changes in the form of the presentation of data in the Nautical Almanac have involved alteration in all astronomical computation forms, of which 10 have been rearranged and reprinted. The new forms are applicable to both the complete and abridged editions of the Almanac.

A form (26 Trian.) has been designed for the correction of the horizontal angles of primary triangulation for dislevelment * due to deviation of the vertical, when the latter is known. This correction has not been applied hitherto, but it was found desirable in the case of the angles of the Kengtung Base-net, where the deviation is large and the rays are steeply inclined.

7. Publications.—The triangulation data for 4 Indian and 19 Persian degree sheets have been compiled. Four Persian pamphlets (8 degree sheets) have been printed and three Indian pamphlets have been reprinted. Addenda to 9 sheets have also been printed.

The levelling pamphlet for 1/M sheet 56 has been reprinted with considerable additions. 170 miles of primary levelling have been printed as addenda, and 3 secondary ines have been reproduced by Gestetner.

Progress is being made with the printing of Auxiliary Tables, Part V, (Lambert Grid), but it is not yet finished. Progress is also being made with the press copy of Auxiliary Tables, Part IV, (Geodetic Tables), which is nearly complete.

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

(a) Geodetic Report, Vol. VI

(b) Auxiliary Tables, Part II. Reprint.

(c) Departmental Paper No. 10. "Hunter Short Base". 2nd edition.

8. Miscellaneous computations.—The gridding of various special maps has necessitated the computation of many sets of grid cutting points on meridians and parallels not included in the regular tables.

Progress has been made with the adjustment of triangulated heights to spirit-levelled values, as the result of connections between bench-marks and minor triangulation carried out by topographical parties.

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* De Graaff Hunter, "Geodesy", Departmental Paper No. 12, pages 42-44.

Instruction has been given to three Class I officers on first joining the department.

9. Drawing Section.—The drawing section has completed the following work.

(*a*) Charts for 21 triangulation pamphlets.
(*b*) Chart for 1 levelling pamphlet.
(*c*) 23 charts and diagrams for Geodetic Report, Volume VI
(*d*) 10 charts for Geodetic Report Volume VII.
(*e*) 5 figures for the Geodetic Handbook, Part I.
(*f*) 3 figures for Departmental Paper No. 10.
(*g*) About 40 miscellaneous charts and figures.

CHAPTER II

OBSERVATORIES

BY CAPTAIN G. BOMFORD, R.E.

1. Standards of length.—The measurement of the Kengtung Base line (see Chapter VI) has necessitated the standardization of the invar wires of the Jäderin equipment. The 24-metre and 4-metre comparators, which were obtained in 1914, have not previously been put to serious use and a considerable amount of time has had to be spent on their adjustment before satisfactory results have been obtained.

The modern standards of the Survey of India consist of:—(1) a nickel metre by the Societè Genevoise d' Instruments de Physique, which was standardized by the National Physical Laboratory in 1914, and (2) a fused silica bar constructed by the N.P.L. and standardized by them in 1925. A comparison between the two standards in 1930, revealed a discrepancy of 6 μ. This necessitated the return of the bars to the N.P.L., who have found that the nickel bar has shortened by 4½ μ since 1914, presumably by reason of some unrecorded ill-treatment between 1914 and 1930.

The sub-standard used in the 24-metre comparator is a 4-metre invar bar, which was standardized by the N.P.L. in 1914. It has been compared with the nickel and silica metres and has been found to have increased in length by 7·5 in 1,000,000 in 16 years. Its coefficient of expansion has been roughly checked and has been found to agree with the certificate within 1 in 10,000,000 per °C. and the original value of the coefficient has been accepted.

The six 24-metre invar wires used were standardized at Sèvres in 1908, since when they have increased in length by about 0·22 mm. in the case of one batch and 0·38mm. in another. Such an increase is to be expected, but it has also been found that the coefficients of expansion quoted in the original certificate are now quite inapplicable. The discrepancy is so great as to have been obvious as soon as the wires were used in the field (see Chapter VI, para 6), and it has been confirmed by direct determination made in the field, and also on the 24-metre comparator at Dehra. Details are given in sub-para c.

The 24-metre comparator was originally designed with auxiliary microscopes for the determination of coefficients of expansion, but the necessary tank (with equipment for circulating and heating the water in it) had never been constructed. This has now been done.

The thermostat for controlling the temperature in the 4-metre comparator was broken in transit from England many years ago. A new thermostat, which was designed and constructed by Mr. G. F. Wood of the Royal Indian Military College, Dehra Dūn, has now been completed and installed.

A full description of the Survey of India comparators is given in "Engineering" Vol. C 1915.

The following paragraphs give details of the observations and of the deduction of the length of the wires and intermediate standards. The observers were Captain G. Bomford and Mr. R. B. Mathur.

(a) Certificates.—The certificates of the bars and wires are as follows:—

Nickel 1-metre, N.P.L., 1931:—

$L_t = L_0\ (1 + 0{\cdot}000\ 012\ 396t + 0{\cdot}000\ 000\ 008\ 36t^2)$

$L_{20} = 1\ \text{metre} + 0{\cdot}2663\text{mm}.$

Silica 1-metre, N.P.L., 1931:—

$L_t = L_0\ (1 + 0{\cdot}000\ 000\ 383t + 0{\cdot}000\ 000\ 000\ 96t^2)$

$L_{20} = 1\ \text{metre} - 0{\cdot}0253\text{mm}.$

Invar 4-metre, N.P.L., 1914:—

$L_t = L_0\ (1 + 0{\cdot}000\ 001\ 450t - 0{\cdot}000\ 000\ 000\ 5t^2)$

$L_{20} = 4$ metres $+\ 0{\cdot}160$ mm on centre line (Baros plugs)
$+\ 0{\cdot}157$ mm on edge A
$+\ 0{\cdot}160$ mm on edge B

24-metre invar wires Nos. 243 & 244, Sèvres 1908:—

$L_t = L_0\ (1 + 0{\cdot}000\ 000\ 302t + 0{\cdot}000\ 000\ 002\ 86t^2)$

No. 243 $L_{15} = 24\,\text{m} - 0{\cdot}74\,\text{mm}$
No. 244 $L_{15} = 24\,\text{m} - 2{\cdot}05\,\text{mm}$

24-metre wires Nos. 247, 248, 249 & 252, Sèvres 1908:—

$L_t = L_0\ (1 - 0{\cdot}000\ 000\ 228t - 0{\cdot}000\ 000\ 000\ 40t^2)$

No. 247 $L_{15} = 24\,\text{m} + 0{\cdot}74\,\text{mm}$
No. 248 $L_{15} = 24\,\text{m} + 0{\cdot}86\,\text{mm}$
No. 249 $L_{15} = 24\,\text{m} + 0{\cdot}63\,\text{mm}$
No. 252 $L_{15} = 24\,\text{m} + 2{\cdot}04\,\text{mm}$

The temperatures referred to in the certificates are all on the hydrogen scale, to which the certificates of the thermometers used also refer.

In the following paragraphs the "reputed length" of a bar means the length according to the above certificates at the temperature of observation.

(b) Coefficient of Expansion of Invar 4-m.—The invar bar was compared against the nickel-steel 4-m sub-standard at temperatures of about 24°C and 33°C, the nickel-steel* being kept at an almost constant temperature. The programme of observation was not a very full one, since the first few observations confirmed the N.P.L. certificates within sufficiently close limits.

Invar 4-m *minus* Nickel-steel 4-m.

Date	Temperature		G.B	R.B.M.
15-10-31 ...	T_I	23°·9	−0·0012mm	−0·0020mm
	T_{NS}	23°·80	−0·0001	−0·0002
		Mean	−0·0007	−0·0011
	T_I	32°·75	+0·0432	+0·0422
	T_{NS}	23°·94	+0·0419	+0·0405
		Mean	+0·0426	+0·0414

Reputed increase in N.S = 0·0042mm
∴Observed increase in Invar = 0·0475 G.B.
or 0·0467 R.B.M.
Temperature range (Invar) = 8°·85C
∴Increase per 4m per °C = 0·0053mm
N.P.L. at 28°C gives 0·0057

The discrepancy is 1 in 10^7 per °C. Since the expansion is only required through a range of 4°C, this has been considered to be sufficient check, and the N.P.L. value has been accepted.

(c) Coefficient of expansion of invar wires.—The coefficients were determined three times in the comparator at temperatures ranging from about 24°C to 36°C. The coefficients of four of the wires were also determined in the field by measurement of a 240-metre length at about 13°C and at 33°C. The results are given below:—

Increase in mm. per 24m per °C.

Tension 10 Kilogrammes. October 1931

	243	244	247	248	249	252
1st comparison... ...	+ ·0081	+ ·0067	− ·0011	− ·0008	− ·0061	+ ·0053
2nd „	− ·0007	+ ·0041	− ·0026	− ·0037	− ·0081	− ·0063
3rd „	+ ·0076	+ ·0051	+ ·0021	− ·0006	− ·0048	− ·0051
Mean	+ ·0050	+ ·0053	− ·0005	− ·0017	− ·0063	− ·0020
Field measure	+ ·0050	+ ·0058	− ·0005	− ·0030	...	...
Accepted Mean for 26°C ...	+ ·0050	+ ·0056	− ·0005	− ·0024	− ·0063	− ·0020
Sèvres 1908	+ ·0111	+ ·0111	− ·0060	− ·0060	− ·0060	− ·0060
Discrepancy	− ·0061	− ·0055	+ ·0055	+ ·0036	− ·0003	+ ·0040

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* From N.P.L. Certificate. 1914, the coefficient of expansion of the nickel-steel bar at 24°C is deduced as + ·030mm per 4m per °C.

The present results are not very consistent, but they clearly contradict the 1908 values, and also they go far to reconcile the discrepancy between pairs of wires used simultaneously in the field. It may be remarked that a figure of 0·0240 in the above table corresponds to 1 : 10^6 per C, and that the mean temperature of the field work was within 2 or 3 degrees of that at which the wires were standardized. The results are thus amply accurate.

The cause of the change is not known. The 1908 determinations were not made on the field wires themselves, but on pieces cut from lengths of the wires from which they were made (243 and 244 were made from one wire: 247, 248, 249 and probably 252 from another). It is not known whether the discrepancy is more likely to be due to this cause or to a subsequent change in the coefficient.

(d) Silica 1-m *minus* Nickel 1-m.—

Date	Temperature *	G.B	R.B.M.
3-10-30 ... Morning	T_S = 24°·74 T_N = 24°·73	−0·3501mm ·3481 ·3476 ·3494	−0·3489mm ·3475 ·3479 ·3460
	Mean	−0·3488	−0·3476
3-10-30 ... Afternoon	T_S = 24°·82 T_N = 24°·86	−0·3491mm ·3543 ·3494 ·3499	−0·3457mm ·3506 ·3535 ·3487
	Mean	−0·3507	−0·3496

		Morning	Afternoon
Reputed length of nickel	=	1m + 0·3267mm	1m + 0·3284mm
Reputed length of silica	=	1m − 0·0233	1m − 0·0232
Reputed silica *minus* nickel	=	− 0·3500	− ·3516
Observed silica *minus* nickel	=	− 0·3482	− ·3502
Discrepancy	=	− ·0018	− ·0014

The discrepancy is 1·6 in 10^6, which shows that the bars were not seriously damaged in transit between Dehra Dūn and England, and that the comparator was in fair working order.

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* In all the measurements in the 4-metre comparator, the temperature of the invar has been given by thermometer No. 18572, that of the silica bar by No. 18571, and that of the nickel bar by the mean of 18571 and 18570 during its comparison with the invar and by No. 18572 while comparing with the silica bar. The thermometer readings have been corrected according to N.P.L. certificates dated 1931.

(e) Invar 4-m *minus* Nickel 1-m.—

First metre (0 to 1) of invar bar.

Date	Temperature	G.B.	R.B.M.
6-10-30 ...	T_I = 23°·4	−0·2530mm	−0·2523mm
	T_N = 23 ·48	·2498	·2509
		·2534	·2496
		·2547	·2522
		·2547	·2510
		·2531	·2520
		·2519	·2488
		·2551	·2553
	Mean	−0·2532	−0·2515

Reputed length of nickel = 1m +0·3107mm
Observed invar *minus* nickel = −0·2524
∴ Length of invar at 23°·4 = 1m +0·0583
and „ „ „ „ 24°·3 = 1m +0·0596

Second metre (1 to 2) of invar bar.

Date	Temperature	G.B.	R.B.M.
6-10-30 ...	T_I = 23°·4	−0·2601mm	−0·2562mm
	T_N = 23 ·47	·2612	·2616
		·2622	·2594
		·2630	·2637
		·2618	·2597
		·2617	·2603
		·2610	·2597
		·2621	·2606
	Mean	−0·2616	−0·2601

Reputed length of nickel = 1m +0·3106mm
Observed invar *minus* nickel −0·2609
∴ Length of invar at 23°·4 = 1m +0·0497
and „ „ „ „ 24°·3 = 1m +0·0510

Third metre (2 to 3) of invar bar.

Date	Temperature	G.B.	R.B.M.
5-10-30 ...	T_I = 23°·9	−0·2653mm	−0·2638mm
	T_N = 23°·97	·2622	·2587
		·2635	·2614
		·2620	·2608
		·2647	·2644
		·2629	·2657
		·2664	·2664
		·2653	·2667
	Mean	−0·2640	−0·2636

Reputed length of nickel = 1m + 0·3170mm
Observed invar *minus* nickel = − 0·2638
∴ Length of invar at 23°·9 = 1m + 0·0532
and „ „ „ „ 24°·3 = 1m + 0·0538

Fourth metre (3 to 4) of invar bar.

Date	Temperature	G.B.	R.B.M.
5-10-30 ...	T_I = 23°·9	−0·2597mm	−0·2612mm
	T_N = 23°·91	·2600	·2590
		·2568	·2555
		·2627	·2638
		·2596	·2567
		·2575	·2555
		·2578	·2545
		·2590	·2575
	Mean	−0·2591	−0·2580

Reputed length of nickel = 1m + 0·3162mm
Observed invar *minus* nickel = − 0·2586
∴ Length of invar at 23°·9 = 1m + 0·0576
and „ „ „ „ 24°·3 = 1m + 0·0582

Combining the four sections of the invar bar gives the total length of the bar as 4m + 0·2226mm at 24°·3C according to comparison with the nickel.

(f) Invar 4-m *minus* Silica 1-m.

First metre (0 to 1) of invar bar.

Date	Temperature	G.B.	R.B.M.
4-10-30 ...	T_I = 24°·3	+ 0·0851mm	+ 0·0872mm
	T_S = 24°·31	·0847	·0792
		·0831	·0788
		·0842	·0772
		·0833	·0794
		·0813	·0826
		·0801	·0794
		·0812	·0823

In the first four sets of observations there are usually large differences between the two observers. During these sets the lighting of the bar seemed peculiar, and was probably responsible for the discrepancies. It is preferred to accept the mean of the last four sets only, viz:—G.B. + 0·0815 and R.B.M. + 0·0809. The general mean of these sets is only 0·0006mm less than the mean of all.

Reputed length of silica = 1m − 0·0235mm
Observed invar *minus* silica = +0·0812
∴ Length of invar at 24°·3 = 1m +0·0577

Second metre (1 to 2) of invar bar.

Date	Temperature	G.B.	R.B.M.
4-10-30 …	T_1 = 24°·3	+0·0747mm	+0·0742mm
	T_2 = 24°·34	·0720	·0750
		·0736	·0754
		·0717	·0747
		·0730	·0733
		·0705	·0708
		·0718	·0728
		·0715	·0691
	Mean	+0·0723	+0·0732

Reputed length of silica = 1m − 0·0235mm
Observed invar *minus* silica = +0·0728
∴ Length of invar at 24°·3 = 1m +0·0493

Third metre (2 to 3) of invar bar.

Date	Temperature	G.B.	R.B.M.
4-10-30 …	T_1 = 24°·4	+0·0769mm	+0·0754mm
	T_2 = 24°·44	·0733	·0758
		·0721	·0748
		·0734	·0730
		·0731	·0729
		·0719	·0709
		·0725	·0733
		·0736	·0741
	Mean	−0·0733	+0·0738

Reputed length of silica = 1m − 0·0234mm
Observed invar *minus* silica = +0·0736
∴ Length of invar at 24°·4 = 1m +0·0502
and „ „ „ „ 24°·3 = 1m +0·0501

Fourth metre (3 to 4) of invar bar.

Date	Temperature	G.B.	R.B.M.
7-10-30 …	T_1 = 23°·9	+0·0786mm	+0·0804mm
	T_2 = 23°·88	·0780	·0771
		·0794	·0813
		·0840	·0875 (Rejected)
		·0802	·0831
		·0772	·0807
		·0765	·0783
		·0796	·0820
		·0801	·0794
	Mean	+0·0787	+0·0803

Reputed length of silica = 1m – 0·0236mm
Observed invar *minus* silica = +0·0795
∴ Length of invar at 23°·9 = 1m +0·0559
and „ „ „ „ 24°·3 = 1m +0·0565

Combining the four sections of the invar bar gives the total length of the bar as 4m + 0·2136mm at 24°·3C according to comparison with the silica 1-m.

The discrepancy of 0·0090mm between the above figure and that given by the nickel bar amounts to 2·2 parts in 1,000,000 which is rather large. The discrepancy is of the same sign in all four sections of the invar bar, and the direct comparison between the nickel and silica bar (sub-para *d*) showed a similar discrepancy of 1·6 in 1,000,000. The error is clearly systematic, not casual. Such an error is likely to be caused either by error in the temperature or by damage to a bar in transit. In both cases the nickel bar is the one more likely to error since the silica bar cannot be damaged without visible breakage. The determination from the silica is therefore given treble weight and the combination of the two determinations gives

4m + 0·2158mm at 24°·3C in 1930.

for the length of the 4-m invar bar (Baros plugs). The 1914 N.P.L. certificate gives 4-m + 0·185mm, whence the rate of growth has been 0·5 per 1,000,000 per annum.

(g) 4-m invar. Edge B *minus* Baros plugs.—

Date	G.B.	R.B M.
6-10-30 ...	+ 0·0039mm	+ 0·0025mm
	– ·0012	+ ·0026
	+ ·0035	– ·0025
	– ·0018	– ·0026
	+ ·0026	– ·0009
	+ ·0001	+ ·0029
Mean ...	+ 0·0012	+ 0·0003

General mean = + 0·0008mm
cf. 0·000 in N.P.L. certificate.
∴ Length of edge B at 24°·3 = 4m + 0·2166mm
and at 28°C. (required below) it is 4m + 0·2376mm

(h) 4-m invar. Edge B *minus* Edge A.—

Date	G.B.	R B.M.
23-8-30 ...	+ 0·0011mm	+ 0·0008mm
	·0016	·0035
	·0048	·0034
	·0023	·0045
	·0020	·0040
	·0067	·0065
	·0007	·0074
	·0058	·0045
Mean	+ 0·0031	+ 0·0045

General mean **B − A = + 0·0038mm.**
cf. + 0·003 in N.P.L. certificate.

(i) 24-metre Comparator.—The six invar wires were hung in the comparator on two different days in August 1930, and again in April 1931 after the field work, the 4-m invar bar being stepped along the comparator before and after the comparison of the wires. The constancy of the length of the comparator depends on an invar tape to which the terminal and intermediate marks are clamped. Its coefficient of expansion has not been directly determined, but it is given with sufficient accuracy by the observations themselves, as shown in Plate III, from which it is seen that the length increases with temperature at the rate of about 0·023mm per 24m per °C.

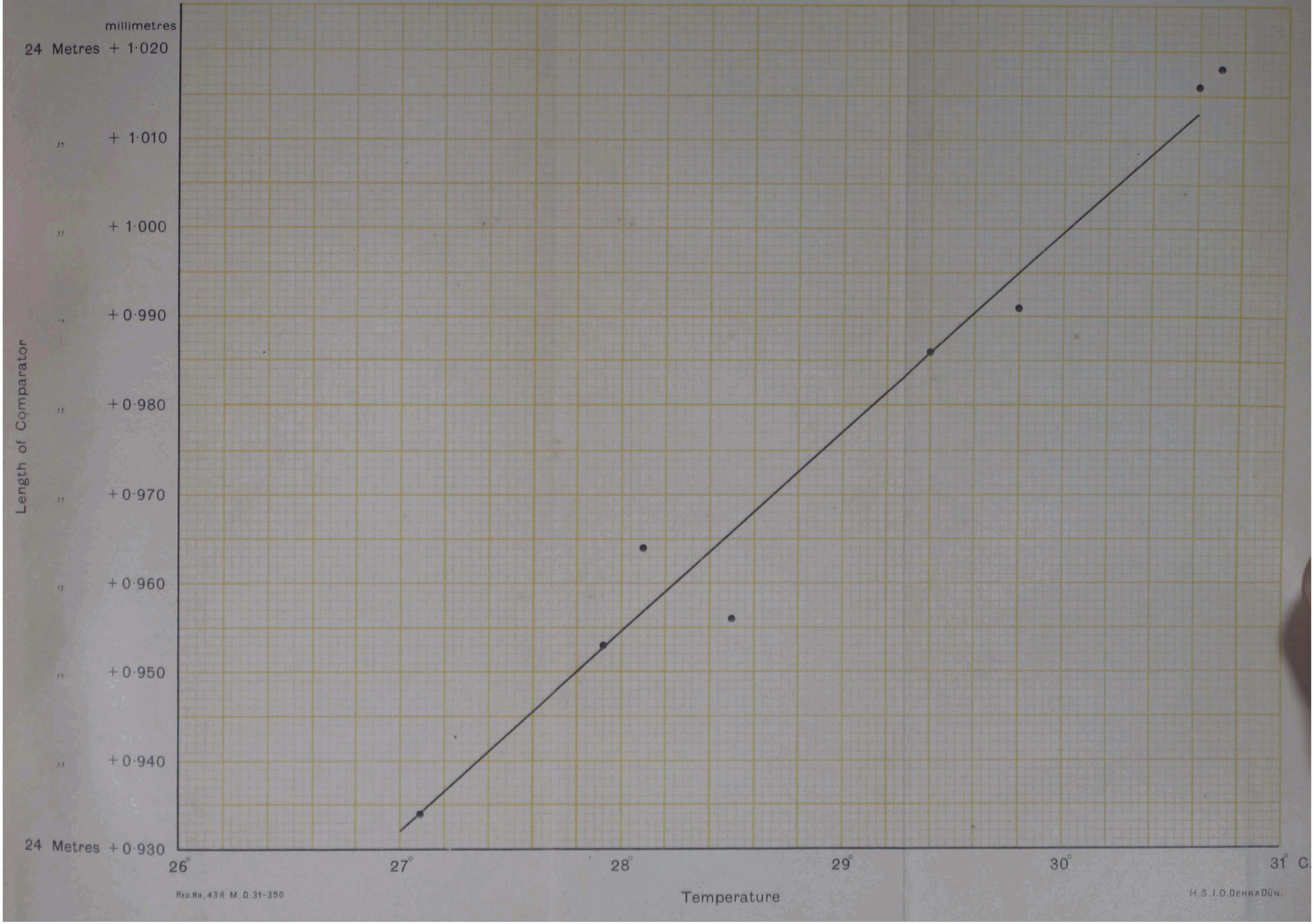
(j) Lengths of 24-m Wires.—

Date	Wire	Temperature	Wire *minus* Base. Observed	Length of wire at 28°C.
19-8-30 ...	243	28°·2	−1·341mm	24m − 0·383mm
	244	28·1	−2·665	−1·709
	247	28·8	+0·095	+1·067
	248	29·0	+0·182	+1·161
	249	28·4	−0·043	+0·923
	252	28·5	+1·400	+2·366
22-8-30 ...	243	28·3	−1·341	−0·382
	244	28·0	−2·675	−1·721
	247	28·3	+0·079	+1·040
	248	28·3	+0·156	+1·118
	249	28·6	−0·035	+0·936
	252	28·6	+1·386	+2·354

24-metre Comparator.

Length at different temperatures in 1930-31

Plate III



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Date	Wire	Temperature	Wire *minus* Base. Observed	Length of wire at 28°C.
21-4-31 ...	243	30·6°	−1·322mm	24m−0·321mm
	244	30·8	−2·745	−1·743
	247	30·2	+0·035	+1·040
	248	30·2	+0·101	+1·110
	249	30·1	−0·002	+1·013
	252	30·2	+1·395	+2·403
23-4-31 ...	243	30·3	−1·348	−0·354
	244	30·4	−2·748	−1·753
	247	30·2	+0·016	+1·021
	248	30·2	+0·114	+1·123
	249	30·1	−0·006	+1·009
	252	30·0	+1·420	+2·423

The results may then be summarized as follows, where the figures are millimetres of excess or defect on 24m at 28 C.

Wire	Length in 1908	19-8-30	22-8-30	Growth since 1908	21-4-31	23-4-31	Growth 1930-31
243	−0·61	−0·38	−0·38	+0·23	−0·32	−0·35	+0·04
244	−1·92	−1·71	−1·72	+0·20	−1·74	−1·75	−0·03
247	+0·66	+1·07	+1·04	+0·39	+1·04	+1·02	−0·02
248	+0·78	+1·16	+1·12	+0·36	+1·11	+1·12	−0·03
249	+0·55	+0·92	+0·94	+0·38	+1·01	+1·01	+0·08
252	+1·96	+2·37	+2·35	+0·40	+2·40	+2·42	+0·05

NOTE:—A discrepancy of 0·024mm per 24m is 1 part in 1,000,000.

The table shows that the growth between 1908 and 1930 has been similar in wires having common origins, viz:— about 0·4 in 1,000,000 per year in the case of 243 & 244, and 0·7 in the others. Its constancy verifies the accuracy of the comparisons. The changes during the field season (the first) have been less regular, as might be expected, but it is surprising that wires 249 and 252, which were used as field standards, should have changed so much more than the other four. Among the latter the mean change has only been 1 : 2,500,000, which is very satisfactory, and the daily comparisons with the field standards have consequently been ignored, and the mean of the August and April standardizations has been accepted, as follows :—

243	**24m−0·36mm**
244	**−1·73**
247	**+1·04**
248	**+1·13**

} at 28°C, in catenary under 10 kilogrammes tension.

(k) Accuracy.—The least accurate part of the work is believed to have been the standardization of the 4-m invar bar in terms of the nickel and silica metres, the difference being 2 : 1,000,000. It is thought that the silica determination is considerably the more reliable, and that the weighted mean is very unlikely to be wrong by more than 1 : 1,000,000. The errors in the other comparisons are much less considerable. Thus the N.P.L. certificates are said to be correct to 0·0003mm (1 in 3,000,000): the comparisons between the centre marks and edges A & B of the 4-m invar bar agree with the old N.P.L. certificates within 1 : 4,000,000 and the close agreement between the August and April standardizations of the four field wires indicates that the error of the mean wire on account of this comparison and of ill-treatment in the field is very unlikely to exceed 1 : 2,000,000.

Taking all sources of error into account it is thought that the error of the mean wire is less than 1 : 1,000,000, and that it is very unlikely to exceed 1½ : 1,000,000.

2. Longitude.—The record of the longitude of Dehra Dūn was maintained, as in previous years, by bi-weekly observations of local time with the bent transit, combined with the reception of the $8^h\ 01^m$ G.M.T. Bordeaux and the $9^h\ 55^m$ or $17^h\ 55^m$ G.M.T. Rugby wireless time signals. The time observer was Mr. H. C. Banerjea. The resulting values of the longitude are given in Table 1, monthly means being as follows:—

	Bordeaux			Rugby
	h	*m*	*s*	*s*
September 1930	5	12	11·80	11·80
October			11·75	11·72
November			11·74	11·75
December			11·81	11·75
January 1931			11·76	11·76
February			11·71	11·75
March			11·73	11·74
April			11·76	11·75
May			11·77	11·74
June			11·73	11·72
July			11·68	11·63
August			11·69	11·71

The value of the longitude of Dehra Dūn obtained in 1926 was $5^h\ 12^m\ 11^s{\cdot}79$, and this value has on the whole been confirmed by work carried out since, although considerable apparent fluctuations have occurred, as shown in Geodetic Report Vol. VI, Plate II. The figures given above serve to extend this diagram another year, and it is noticeable that the low values obtained in 1930 seem to be continuing.

The value of the bubble correction was kept very small throughout the year, and any doubt as to the value of one division of the bubble has no significance.

The Riefler clock ran regularly during the year, with no leakage of the clock case, except that the pressure suddenly rose to atmospheric on Dec. 7th. The error, rate, pressure and temperature are given in Table 2.

The Shortt clock has been erected and started, but has not been put into regular use. Stoppages have occurred on account of adhesion between the arm of the synchronising switch and the core of the magnet which pulls it down. Similar trouble has also occurred with the resetting lever in the master clock. The trouble is a trivial one, but pressure of other work has prevented much attention being given to the matter.

3. Latitude variation.—As stated in last year's report a variation of latitude programme was begun in February 1930. The observations have been continued by Computer Jagdish Behari Mathur, and the results of the first year's work have been computed. The results, which are given on page 28, are thought to indicate that a sufficient degree of accuracy is being maintained, although several years' work will be necessary before final results can be given.

Table 3 shows the groups which have been used to form the chain*, and the mean differences of latitude as determined by successive pairs of groups. The final closing error of $0''\cdot22$ is thought not to be excessive. It has been distributed in accordance with the probable errors given.

Table 4 shows the monthly mean values of latitude, and their departures from the annual mean. The variation indicated is not dissimilar to that given by the three international stations, although the amplitude given by Dehra is considerably larger.

The work is being continued.

4. Seismograph and Meteorological observations.—The Omori seismograph was in operation throughout the year, an exceptionally large number of earthquakes being recorded, of which a full list is given in Table 5. Good records were obtained of the Burma earthquake of 28-1-31, the very great earthquake of 11-8-31 in Mongolia of which no local reports have yet been received, and of the series of shocks near Quetta in August 1931.

Meteorological observations have been made at 8.00 and 17.00 hours throughout the year.

5. Miscellaneous work.—A new model of the Hunter Short Base (see Plate VIII) has been constructed, and six sets have been

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[*] This programme was suggested by the Astronomer Royal. It has considerable advantages over the International chain of 12 groups.

obtained from the Mathematical Instrument Office, Calcutta. The descriptive booklet, Departmental Paper No. 10, has been brought up-to-date and re-written by Mr H. C. Banerjea.

The levels of the levelling party were tested, and the standard tapes standardized, before and after the field season. Four new types of level and one rustless steel tape were tested and reported on.

TABLE 1.—*Variation of Longitude of Dehra Dūn from accepted value, as determined from reception of wireless time signals from Bordeaux and Rugby, 1930-31.*

Date (Greenwich)	Observed value *minus* accepted value*		Date (Greenwich)	Observed value *minus* accepted value*	
	Bordeaux	Rugby		Bordeaux	Rugby
1930			1931		
	s	s		s	s
Sept. 2	+ 0·07	+ 0·03	Jan. 12	− 0·01	− 0·01
5	+ 0·08	+ 0·08	15	− 0·01	− 0·02
8	+ 0·04	+ 0·01	17	− 0·02	− 0·02
15	− 0·03	0·00	20	− 0·04	− 0·01
19	− 0·01	− 0·01	26	− 0·13	− 0·13
22	− 0·02	− 0·01	29	− 0·11	− 0·08
26	− 0·04	0·00	Feb. 4	− 0·03	− 0·02
29	0·00	+ 0·02	11	− 0·11	− 0·04
Oct. 3	...	− 0·01	14	− 0·09	− 0·04
7	− 0·06	− 0·06	19	− 0·03	+ 0·01
10	− 0·01	− 0·05	24	− 0·14	− 0·12
13	− 0·03	− 0·09	Mar. 4	+ 0·01	0·00
17	+ 0·01	− 0·07	7	− 0·08	− 0·07
20	− 0·02	− 0·04	11	− 0·08	− 0·07
24	− 0·11	− 0·15	14	− 0·04	− 0·04
28	− 0·08	− 0·08	17	− 0·09	− 0·05
Nov. 4	...	0·00	22	− 0·09	− 0·06
7	...	− 0·01	25	− 0·08	− 0·08
11	+ 0·02	+ 0·05	28	− 0·05	− 0·04
14	− 0·06	− 0·05	April 2	− 0·01	− 0·03
17	− 0·07	− 0·08	8	− 0·05	− 0·01
22	− 0·08	− 0·09	12	− 0·01	+ 0·01
25	− 0·05	− 0·07	15	− 0·09	− 0·08
Dec. 1	− 0·05	− 0·09	18	...	− 0·04
5	− 0·01	− 0·06	22	− 0·04	− 0·12
9	− 0·01	...	25	− 0·01	+ 0·01
11	+ 0·06	− 0·03	28	− 0·01	− 0·04
16	+ 0·07	0·00	May 1	− 0·01	− 0·08
19	+ 0·03	− 0·01	5	...	− 0·13
22	+ 0·02	− 0·02	9	− 0·04	− 0·04
26	+ 0·01	− 0·04	11	− 0·01	− 0·02
31	0·00	− 0·04	14	− 0·04	− 0·09
1931			18	− 0·01	− 0·01
Jan. 5	+ 0·06	+ 0·05	21	+ 0·01	+ 0·02
8	+ 0·02	+ 0·02	30	− 0·07	− 0·04
			June 2	− 0·04	− 0·04

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

(*Continued*)

TABLE 1.—*Variation of Longitude of Dehra Dūn from accepted value, as determined from reception of wireless time signals from Bordeaux and Rugby, 1930-31—(concld.).*

Date (Greenwich)	Observed value *minus* accepted value*		Date (Greenwich)	Observed value *minus* accepted value*	
	Bordeaux	Rugby		Bordeaux	Rugby
1931			1931		
	s	*s*		*s*	*s*
June 5	...	− 0·05	July 15	− 0·08	− 0·15
9	...	− 0·04	31	− 0·09	− 0·14
12	...	− 0·04	Aug. 14	− 0·10	− 0·08
16	...	− 0·03	17	− 0·09	− 0·09
19	− 0·02	− 0·08	22	− 0·09	− 0·07
26	− 0·09	− 0·11	26	− 0·12	− 0·10
29	− 0·09	− 0·15			
July 7	− 0·13	− 0·19			
10	− 0·14	− 0·18			

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

NOTE :—In the above table one value of the longitude is given by the association of each observation of local time with the wireless signal received at the least interval from it i.e., generally either during the same night or preceding afternoon. Results are give up to August inclusive after which the corrections to the times of emission are not yet available. Individual night's observations have not been smoothed to give a more uniform clock error. The reputed times of emission of the wireless signals have been corrected by the amounts given in the Admiralty Notices to Mariners in the case of Rugby signals, and by the demi-definatif corrections of the Bulletin Horaire in the case of Bordeaux signals. When deducing the longitude from the latter, a correction of $0^{s}{\cdot}02$ has been added to the reputed Greenwich time of emission, on account of this having been computed (by the Bulletin Horaire) on the assumption that the longitude of Paris is $0^{h}\ 9^{m}\ 20^{s}{\cdot}93$, whereas the more recent value is $0^{h}\ 9^{m}\ 20^{s}{\cdot}91$ (*See* La Participation Francaise à la Revision des Longitudes Mondiales, Lambert, p.103). The speed of propagation has been taken to be 300,000 km. per second.

TABLE 2.—*Error, rate, temperature and pressure of Riefler clock No. 450, by the bent transit instrument, at 20 hrs. Indian standard time, 1930-31.*

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	
1930	*m* *s*			*s*	mm	C	
Oct. 3	+0 31·96	5	5	+0·11	596	° 26·6	
7	32·45	5	5	+0·12	596	26·6	
10	32·75	5	5	+0·10	596	26·7	
13	33·14	5	4	+0·13	596	26·7	
17	33·60	4	4	+0·12	596	26·7	
20	33·96	5	5	+0·12	596	26·6	
24	34·54	5	5	+0·15	596	26·7	
28	35·08	5	5	+0·13	596	26·6	
Nov. 4	36·05	5	5	+0·14	595	26·5	
7	36·48	4	6	+0·14	596	26·9	
11	36·93	5	5	+0·11	596	26·9	
14	37·27	5	5	+0·11	598	26·6	
17	37.53	5	5	+0·09	598	26·6	
22	38·03	5	5	+0·10	598	26·6	
25	38·29	5	5	+0·09	598	26·6	
Dec. 1	38·54	5	5	+0·04	598	26·6	
5	38·50	5	5	−0·01	598	26·7	
9	36·58	5	5	.	600	26·6	Pressure rose to 710mm due to leakage on 7th. It was adjusted and reduced to 600mm on 8th Dec.
11	36·59	5	5	+0·01	600	26·7	
16	36·68	5	5	+0·02	600	26·7	
19	36·77	5	5	+0·03	600	26·6	
22	36·92	5	5	+0·05	600	26·6	
26	37·13	5	5	+0·05	600	26·5	
31	37·39	5	5	+0·05	599	26·6	
1931							
Jan. 5	37·51	5	5	+0·02	598	26·5	
8	37·66	5	5	+0·05	598	26·6	
12	37·83	4	5	+0·04	598	26·7	
15	38·04	5	5	+0·07	598	26·4	
17	38·17	5	5	+0·07	598	26·5	
20	38·28	4	6	+0·04	598	26·7	
26	38·61	5	6	+0·06	598	26·6	
29	38·70	5	6	+0·03	598	26·6	
Feb. 4	38·88	5	7	+0·03	598	26·6	

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

(*Continued*)

TABLE 2.—*Error, rate, temperature and pressure of Riefler clock No. 450, by the bent transit instrument, at 20 hrs. Indian standard time, 1930-31—(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	
1931		*m*	*s*			*s*	mm	C	
Feb.	11	+0	39·21	6	5	+0·05	598	°27·0	
	14		39·11	6	4	−0·03	598	27·1	
	19		39·31	4	6	+0·04	598	26·5	
	24		39·61	5	5	+0·06	598	26·8	
Mar.	4		39·91	5	5	+0·04	598	26·8	
	7		40·14	5	5	+0·08	598	26·4	
	11		40·33	5	5	+0·05	598	26·8	
	14		40·41	4	7	+0·03	598	26·9	
	17		40·55	5	5	+0·05	598	26·7	
	22		40·82	5	5	+0·05	598	26·2	
	25		40·93	5	5	+0·04	598	26·7	
	28		40·99	4	4	+0·02	598	26·8	
Apr.	2		41·23	5	5	+0·05	598	26·7	
	8		41·45	5	5	+0·04	598	26·8	
	12		41·51	5	5	+0·02	598	26·9	
	15		41·64	5	5	+0·04	598	26·8	
	18		41·58	5	5	−0·02	598	26·9	
	22		41·79	5	5	+0·05	598	26·6	
	25		41·69	5	5	−0·03	598	26·8	
	28		41·81	5	6	+0·04	598	26·6	
May	1		41·92	4	4	+0·04	599	26·8	
	5		42·11	5	5	+0·05	598	26·7	
	9		42·15	5	5	+0·01	598	26·8	
	11		42·28	5	5	+0·07	598	26·6	
	14		42·49	4	4	+0·07	598	26·6	
	18		42·57	5	5	+0·02	598	26·7	
	21		42·66	4	4	+0·03	598	26·9	
	30		43·15	5	5	+0·05	598	26·7	
June	2		43·34	5	5	+0·06	597	26·3	
	5		43·51	4	5	+0·06	598	26·6	
	9		43·63	5	5	+0·03	598	26·8	
	12		43·73	5	6	+0·03	598	27·0	
	16		43·88	5	5	+0·04	598	26·7	
	19		44·09	5	5	+0·07	598	27·0	
	26		44·51	5	5	+0·06	598	26·9	
	29		44·75	5	5	+0·08	598	26·8	

* +^{ve} rate = gaining, −^{ve} rate = losing

(Continued)

TABLE 2.—*Error, rate, temperature and pressure of Riefler clock No. 450, by the bent transit instrument, at 20 hrs. Indian standard time, 1930-31—(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	
1931	*m* *s*			*s*	mm	C °	
July 7	+0 46·00	5	5	+0·16	598	27·0	
10	46·56	5	5	+0·19	598	26·7	
15	47·47	5	4	+0·18	598	26·8	
31	50·82	5	5	+0·21	598	26·9	
Aug. 14	53·55	5	5	+0·20	598	26·7	
17	54·17	3	3	+0·21	598	26·7	
22	55·18	6	3	+0·20	598	26·8	
26	0 56·05	5	5	+0·22	598	26·7	
Sept. 14	1 01·00	4	3	+0·26	598	26·5	
16	01·35	5	5	+0·18	598	26·8	
18	01·83	5	5	+0·24	598	26·7	
22	02·84	5	5	+0·25	598	26·6	
25	03·58	3	3	+0·25	598	26·7	
30	+1 04·89	6	6	+0·26	598	26·7	

* +^{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	2nd Feb. 30 to 6th April 30	−0·13 ± ·03
II—III	12 22 to 14 50	16 00 to 18 04	13th April 30 to 30th May 30	−0·22 ± ·03
III—IV	16 00 to 18 04	18 56 to 20 58	5th June 30 to 8th Aug. 30	+0·26 ± ·06
IV—V	18 56 to 20 58	22 11 to 1 04	15th Aug 30 to 10th Oct. 30	+0·14 ± ·04
V—VI	22 11 to 1 04	3 04 to 5 14	1st Oct. 30 to 28th Nov. 30	+0·11 ± ·03
VI—I	3 04 to 5 14	8 18 to 10 09	2nd Dec. 30 to 4th Feb. 1931	+0·06 ± ·03
			Closing error ...	+0·22

TABLE 4.—*Latitude variation*

Preliminary Results

Month	Monthly mean Latitude	Residuals Month *minus* Year
February 1930.	30° 18′ 51″·68	+ 0″·15
March ..	51·46	− 0·07
April ..	51·47	− 0·06
May ..	51·38	− 0·15
June ..	51·28	− 0·25
July ..	51·34	− 0·19
August ..	51·32	− 0·21
September ..	51·43	− 0·10
October ..	51·79	+ 0·26
November ..	51·82	+ 0·29
December ..	51·78	+ 0·25
January 1931.	51·66	+ 0·13
	Annual mean 51·53	...

TABLE 5.—*Earthquakes recorded at Dehra Dūn during 1930-31.*

No.	Date	Indian standard time					Intensity of record	Distance	REMARKS
		1st P. T.	2nd P. T.	Long wave	Maximum	Finish			
	1930	*h m s*	*h m s*	*h m s*	*h m*	*h m*		*miles*	
1	Oct. 1	3 01 20†	3 06 00†	3 10 30	3 12	...	slight	2000	
2	„ 2	21 09 10†	21 12 00†	21 14 30	21 19	21 42	slight	1100	
3	„ 10	3 09 30†	3 10 40†	3 11 50	3 13	...	slight	500	
4	„ 10	...	...	6 17 10†	6 17	...	slight	...	
5	„ 24	16 31 10	16 34 10	16 37 20†	16 42	16 59	slight	1200	
6	„ 25	1 56 20	2 04 50	2 15 20	2 21	...	moderate	4400	
7	„ 29	...	...	3 15 00†	3 17	...	slight	...	
8	Nov. 4	21 11 40†	21 15 40	21 18 00	21 18	22 05	slight	1500	
9	„ 10	0 49 20†	0 57 20	1 04 20	1 18	2 25†	slight	3800	
10	„ 10	...	19 33 30	...	...	...	slight	...	
11	„ 26	...	0 49 20	0 56 40	1 02	2 16	great	3400	Destructive in Japan.
12	Dec. 2	12 34 50	12 38 30	12 41 10	12 42	13 22	slight	1400	
13	„ 4	...	...	...	...	...	great	...	Lower Burma. Not recorded, clock stopped.
14	„ 8	13 44 50†	13 49 10†	13 52 50†	13 56	14 20	slight	1800	
	1931								
15	Jan. 2	5 30 30†	5 40 30†	5 48 20†	5 50	6 24	slight	4900	
16	„ 2	15 41 30†	15 45 00†	15 49 30†	...	...	slight	1600	
17	„ 7	7 36 00†	7 44 40†	7 53 20†	...	...	slight	4300	
18	„ 13	2 13 20†	2 22 40†	2 40 00†	2 42†	3 23	slight	5800	
19	„ 15	7 41 10†	7 53 10	8 12 40	8 47	...	great	7600	Mexico.
20	„ 16	2 44 30†	2 49 30†	2 55 00	2 56	4 02	slight	2200	
21	„ 16	4 24 00†	4 29 10†	4 33 50	4 34	5 45	slight	2200	
22	„ 17	1 54 00†	2 01 20	2 12 50	2 14	3 10	slight	4000	
23	„ 17	9 04 40†	9 13 10	9 27 10	9 37	10 13	slight	4900	
24	„ 20	14 59 30	15 00 20	15 01 10	15 01	15 23†	slight	300	
25	„ 24	19 27 20†	19 33 20†	19 39 30	19 47†	20 12	slight	2800	
26	„ 28	1 43 50	1 46 40	1 48 30	1 53	3 46	great	1100	Burma.
27	„ 29	3 05 10	3 13 20	3 20 40†	3 31†	4 54	slight	3900	
28	Feb. 3	4 38 00	4 48 00	4 59 20	5 23	7 05	moderate	5400	New Zealand.
29	„ 10	6 59 10†	7 01 50	7 04 40	7 05	7 51†	slight	1100	
30	„ 12	1 23 00†	1 24 50	1 27 20†	1 28	1 53	slight	800	
31	„ 12	11 21 40	11 28 10	11 37 30	11 41	12 28	slight	3400	
32	„ 13	6 18 30†	...	6 24 20	...	6 55	slight	1300	
33	„ 13	7 17 00	7 26 40	7 45 30†	8 02	9 51	moderate	6300	
34	„ 14	19 38 20	19 45 10	19 55 20	19 58	20 36	moderate	3700	
35	„ 19	23 18 30†	23 24 50†	23 34 30†	23 37†	0 55†	slight	3400	
36	„ 20	11 11 20	...	11 17 50	11 18	11 56†	slight	1500	
37	„ 27	15 17 20	15 24 20	15 32 30	15 34	15 56†	slight	3500	
38	Mar. 8	7 29 20	7 36 00	7 48 40	7 54	8 21†	slight	3900	Destructive in the Balkans.

† Recognised with difficulty.

(Continued)

TABLE 5.—*Earthquakes recorded at Dehra Dūn during 1930-31—(contd.).*

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*	
39	Mar. 9	9 33 00	9 40 30	9 51 30	9 57	10 55	great	4100	
40	„ 11	18 06 30	18 14 30	18 29 10	18 33	18 53	slight	4700	
41	„ 18	13 49 10	...	14 53 20	15 11	15 48	slight	...	
42	„ 19	1 52 10	1 55 50	1 59 50	2 16	2 49	slight	1600	
43	„ 19	3 42 30†	...	...	...	4 07†	slight	...	
44	„ 19	12 02 30	12 08 30	12 14 50	12 21	12 58	slight	2800	
45	„ 28	18 19 00	18 24 00	18 29 30	18 30	19 17	slight	2200	
46	Apr. 27	22 26 20	22 31 20	22 37 30	22 40	23 20	slight	2300	
47	May 20	8 04 10	8 13 40	8 29 50	8 36	9 24	slight	5700	
48	June 18	18 30 10†	18 31 20	18 32 00	18 32	18 46	slight	400	
49	„ 25	5 21 00†	5 25 30	5 37 50†	5 39	5 54	slight	2900	
50	July 12	22 23 40†	22 30 20	22 34 30†	22 36	23 27	slight	2800	
51	„ 15	22 13 10†	22 20 20†	22 25 50†	22 27	22 57	slight	3200	
52	Aug. 7	7 52 50†	8 02 10	8 10 10†	8 03	9 13	slight	4600	
53	„ 11	2 52 40	2 56 30	...	3 04	5 20	v. great	1500	Mongolia.
54	„ 11	12 37 10†	12 41 20†	12 46 00†	12 47	13 05	slight	1800	
55	„ 11	23 03 50†	23 09 50†	23 17 50†	23 23	23 52	slight	3000	
56	„ 18	19 54 50	19 58 40	20 01 40	20 05	21 35	great	1500	Mongolia.
57	„ 25	3 07 40	3 09 10	3 10 30	3 13	4 33	v. great	500	Destructive in Quetta, Baluchistān.
58	„ 25	5 02 50†	5 04 00†	5 05 20	5 06	5 25	slight	500	Probably near Quetta.
59	„ 25	...	6 04 50†	6 06 20†	6 06	6 24	slight	800	
60	„ 25	8 40 00†	8 41 30†	8 43 30†	8 42	9 06	slight	600	
61	„ 25	21 16 00†	...	...	21 24	21 36	slight	...	
62	„ 26	13 28 40†	...	...	13 35	13 59	slight	...	
63	„ 26	16 20 50†	16 24 50†	16 28 20	16 29	16 49	slight	1600	
64	„ 26	20 49 20†	...	...	20 58	21 11	slight	...	
65	„ 27	1 04 10	1 05 30	1 07 00	1 07	1 12	slight	600	
66	„ 27	21 00 10	21 01 30	21 03 00	21 05	23 17	v. great	500	Destructive in Quetta, Baluchistān.
67	„ 27	23 32 20†	23 35 00	23 37 00†	23 37	23 53	slight	1000	Probably near Quetta.
68	„ 28	0 16 20†	0 19 00†	0 20 50	0 21	0 38	slight	1000	
69	„ 28	1 35 50†	1 38 20†	1 40 00†	1 42	1 52	slight	900	
70	„ 28	6 14 30†	6 17 50	6 20 10†	6 23	6 32	slight	1200	
71	„ 28	13 19 20†	13 21 30†	13 24 20†	13 25	13 38	slight	1000	
72	„ 28	15 45 00†	15 46 20	15 48 40†	15 50	16 02	slight	600	
73	„ 28	23 46 20†	...	23 50 10†	23 51	0 03	slight	800	
74	„ 29	1 12 40	1 15 20	1 17 20	1 18	1 49	slight	1000	

† Recognised with difficulty.

(Continued)

TABLE 5.—*Earthquakes recorded at Dehra Dūn during 1930-31—(concld.).*

No.	Date	Indian standard time					Intensity of record	Distance	REMARKS
		1st P. T.	2nd P. T.	Long wave	Maximum	Finish			
		h m s	*h m s*	*h m s*	*h m*	*h m*		*miles*	
75	Aug. 29	2 57 20†	...	...	2 59	3 21	slight	...	Probably near Quetta.
76	" 29	11 33 30†	11 36 20	11 38 50	11 40	11 50	slight	1100	
77	" 29	18 75 50†	19 00 50†	19 02 50†	19 05	19 20	slight	1100	
78	" 30	1 23 00†	...	1 27 50†	1 29	1 35	slight	1100	
79	" 30	2 10 30†	...	...	2 11	2 25	slight	..	
80	Sept. 6	...	...	11 16 30†	11 21	11 38	slight	...	
81	" 6	20 06 00	20 07 50	...	20 12	20 23	slight	700	Probably near Quetta.
82	" 8	21 45 40	21 47 10†	...	21 50	22 06	slight	500	
83	" 10	2 17 50†	...	...	2 27	2 59	slight	...	
84	" 21	8 06 20†	8 11 20†	8 17 00	8 18	9 03	slight	2300	Japan.
85	" 21	16 04 00†	16 09 50	16 16 10	16 18	16 58	slight	2700	
86	" 25	11 38 40†	11 44 30	11 51 20	11 58	13 58†	v. great	2800	
87	" 30	16 50 50	16 52 00	16 53 00	16 57	17 02	slight	400	
88	" 30	18 31 30†	...	18 33 10	18 34	18 48	slight	400	

† Recognised with difficulty.

CHAPTER III

TIDES

BY CAPTAIN G. BOMFORD, R.E.

1. Tidal observations.—During the year under report registration by automatic tide-gauges was continued at the following stations:—Aden, Basrah, Karāchi (Manora), Bombay (Apollo Bandar), Madras, Calcutta (Kidderpore) and Rangoon. These observations were carried out under the supervision of the Survey of India, immediate control of each observatory being entrusted to the local officers of the port concerned. Automatic registrations were also continued at Colombo and Trincomalee under the supervision of the Superintendent Trigonometrical Surveys, Ceylon, who supplied a new value of the mean sea-level at these places.

In addition, the actual times and heights of high and low waters were observed on tide-poles (during daylight only) under the supervision of the local port officials at Bhāvnagar, Chittagong, and Akyab. The day and night observations at Pilakāt or Deserters' Creek (Rangoon River) were discontinued from 1st April 1931.

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

2. Inspections.—No inspections were made by the Survey of India. The tidal observatory at Aden was inspected by the Port Engineer during March and May 1931, i.e. before and after the dismantling of the gauge for reconstruction of the observatory. The Bombay gauge was inspected by the Port Trust Surveyor. No inspection reports were received from the port authorities at Basrah, Karāchi, Madras, Kidderpore or Rangoon.

All the automatic records have been continuous and satisfactory except for a long break from 4th March to 18th May at Aden Observatory, necessitated by the renewal of its structure, a break from 9th Jan. to 27th April at Basrah due to the removal of the gauge from Tanumah to Wharf A Margil, and a few minor stoppages.

3. Harmonic analysis.—Arrangements were made for the Port Officer, Orissa Ports, to supply the hourly day and night readings at Chāndbāli and Shortt's Island with a view to the determination of the necessary constants for future predictions of the tides at these places. It is hoped to include these predictions in the tide-tables of the Indian Ocean for 1935. The data for both these ports begin from 1st May 1931.

4. **Corrections to predictions.**—Tables 1 & 2 give the corrections that have been applied to the predicted values of the tides for 1932, in the case of Chittagong and Rangoon respectively. The corrections for Rangoon differ very slightly from those used in the previous year and are similarly derived. In the case of Chittagong a mean correction derived from several years actual and predicted values had hitherto been used for the whole year, but for the 1932 predictions fortnightly corrections have been applied, based on the comparisons of predicted and actual values for the period 1923-30. The corrections used for Kidderpore for 1932 tide-tables are the same as those during the previous year.

5. **Tide-tables.**—The tide-tables for the year 1932 have been prepared and issued. They contain information similar to that in the previous volume, as reported in Geodetic Report Vol. VI. Separate small tide-tables in pamphlet form have also been published for Bombay, the Hooghly River and the Rangoon River. Advance predictions for Suez, Aden, Bushire, Karāchi, Bhāvnagar, Bombay, Mormugao, Colombo, Trincomalee, Madras, Dublat, Chittagong, Elephant Point and Mergui, were sent to the Hydrographer to the Admiralty in December 1930, for inclusion in the 1932 Admiralty tide-tables. Advance predictions for Dublat, Madras, Colombo, Bombay and Karāchi were also sent to the Director of the U. S. Coast and Geodetic Survey in exchange for information received from him.

The amount realized by the sale of tide-tables during the year ending 30th September 1931 was Rs. 6,842-12-0, exclusive of agents' commission and the cost of copies issued gratis.

6. **Accuracy of predictions.**—Tables 4 to 16 have been prepared from comparisons made between predicted and actual times and heights of high and low waters at the 9 stations where automatic tide-gauges were in operation, and the 4 stations at which tide-poles were in use. The 1930 predictions for Aden, Basrah, Madras and Kidderpore are practically of the same standard as those of the previous years. Rangoon appears somewhat better, whilst Bombay and Karāchi show a slight deterioration chiefly as regards the number of errors exceeding 30 minutes and 1·0 feet. The greatest differences between the predicted and actual heights of low water, as registered by the automatic tide-gauges at the riverain ports were as shown in Table 3.

TABLE 1.—*Corrections applied to Chittagong for 1932.*

Month	Tide	Dates			
		1st-15th		16th-31st	
		Time *m*	Height *ft.*	Time *m*	Height *ft.*
January ...	High	+ 11	+ 0·2	+ 9	+ 0·2
	Low	+ 10	+ 0·7	+ 8	+ 0·7
February ...	High	+ 7	+ 0·2	+ 7	+ 0·1
	Low	+ 6	+ 0·7	+ 5	+ 0·6
March ...	High	+ 7	0·0	+ 7	0·0
	Low	+ 5	+ 0·6	+ 7	+ 0·5
April ...	High	+ 7	0·0	+ 10	– 0·1
	Low	+ 9	+ 0·5	+ 11	+ 0·4
May ...	High	+ 12	– 0·2	+ 10	+ 0·1
	Low	+ 12	+ 0·4	+ 12	+ 0·7
June ..	High	+ 9	+ 0·3	+ 10	+ 0·1
	Low	+ 12	+ 1·0	+ 10	+ 0·8
July ...	High	+ 10	0·0	+ 9	+ 0·1
	Low	+ 8	+ 0·6	+ 9	+ 0·7
August ...	High	+ 9	+ 0·2	+ 12	+ 0·1
	Low	+ 9	+ 0·8	+ 13	+ 0·8
September	High	+ 15	+ 0.1	+ 19	+ 0·2
	Low	+ 16	+ 0·8	+ 19	+ 0·9
October ...	High	+ 22	+ 0·2	+ 22	+ 0·1
	Low	+ 22	+ 0·9	+ 23	+ 0·7
November ...	High	+ 22	+ 0·1	+ 19	+ 0·2
	Low	+ 23	+ 0·6	+ 18	+ 0·7
December ...	High	+ 16	+ 0·3	+ 13	+ 0·2
	Low	+ 14	+ 0·7	+ 12	+ 0·7

The above corrections are based on the mean fortnightly results of comparisons between predicted and actual times and heights from 1923 to 1930.

TABLE 2.—*Time corrections applied to Rangoon for 1932.*

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

The above corrections are based on the mean fortnightly results of the comparisons between predicted and actual times from 1926 to 1930.

TABLE 3.—The greatest differences between the predicted and actual heights of low water for 1930 at riverain ports were as follows:—

Serial number	Port	Predicted *minus* actual in feet	Date
1	Kidderpore ...	+ 3·5	Morning 19th Sept. 1930.
2	Rangoon ...	− 2·3	Afternoon 12th May 1930.
3	Basrah ...	+ 3·9	Morning 10th June 1930.

TABLE 4.—*Mean errors E_1 and E_2 for 1930.*

ADEN

PERIOD 1930	MEAN ERRORS (Predicted – actual)												Number errors		
	E_1*								E_2*				*30 minutes* of time		
	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.	
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*			
	+	−	+	−	+	−	+	−							
Jan. 1-15	0·7		0·0		2·6			0·1	8·9	0·1	11·4	0·1	0	1	0
16-31		23·6	0·2		0·5		0·2		27·7	0·2	8·7	0·2	6	1	0
Feb. 1-15	1·6		0·0		4·6			0·0	5 5	0·1	9·5	0·1	0	0	0
16-28		31·5	0·2		4·0		0·2		37·9	0·2	11·3	0·2	7	0	0
Mar. 1-15	5·8		0·2		8·1		0·2		10·3	0 2	12·2	0·2	1	1	0
16-31		4 3	0·1		2·4		0·1		13·1	0·1	14·2	0·1	1	2	0
April 1-15	7·1		0·1			5·9	0 1		15·1	0·1	9·9	0·2	2	1	0
16-30		6·9	0·0			10·9	0·0		18·4	0·1	19·8	0·1	3	2	0
May 1-15	2·8		0·1			3·8	0·2		7·8	0·1	8·4	0·2	1	0	0
16-31	3·9		0·2		7·8		0·1		13·5	0·2	18·8	0·2	4	4	0
June 1-15	6·5			0·0	3·7		0·0		9·9	0·1	8·2	0·1	0	0	0
16-30	12·8		0·1		10·0		0·1		20·1	0·1	13·4	0·1	5	3	0
July 1-15	0·1		0·2		9·9		0·2		11·4	0·2	13·2	0·2	0	1	0
16-31	3·4		0·1		5·9		0·1		13·8	0·2	8·4	0·1	1	1	0
Aug. 1-15	0·3		0·2		7 1		0 2		13·2	0·2	9·4	0·2	2	0	0
16-31	8·1		0·2		6·4		0·1		12·7	0·2	8·7	0·2	3	0	0
Sept. 1-15		1·2		0 0	3 5			0·1	11·9	0·2	11·7	0·1	2	1	0
16-30		0·8	0·1		6·5		0·0		18 7	0·1	8·1	0·2	4	0	0
Oct. 1-15		2·6	0·1		2 0		0·1		9·4	0·2	10·8	0·1	1	1	0
16-31		2·8	0·2			0·9	0·1		12·6	0·2	7·7	0·1	3	0	0
Nov. 1-15	1·0		0·1			0·8	0·1		7·6	0·2	9·5	0·2	0	1	0
16-30	1·5		0·3			1·1	0·2		8·7	0·3	10·3	0·2	1	2	0
Dec. 1-15	0·7		0·1		5·0		0·2		8·4	0·2	9·0	0·2	1	1	0
16-31		1·4	0·3			0·5	0·2		10·4	0·3	9·3	0·2	1	1	0
TOTALS ..	56·3	75·1	3·1	0·0	90·0	23·9	2·7	0·2	327·0	4·1	261·9	3·8	49	24	0
MEANS ...	− 0·8		+ 0·1		+ 2 8		+ 0·1		13·6	0·2	10·9	0·2			

TABLE 5.—*Mean errors E_1 and E_2 for 1930.*

BASRAH

PERIOD 1930	MEAN ERRORS (Predicted − actual) E_1* H. W. Time minutes +	−	H. W. Height feet +	−	L. W. Time minutes +	−	L. W. Height feet +	−	E_2* H. W. Time minutes	H. W. Ht. feet	L. W. Time minutes	L. W. Ht. feet	Number of errors exceeding 30 minutes of time H. W.	L. W.	0·5 feet of height H. W.	L. W.
Jan. 1-15		2·0		0·3	30·6			0·2	37·6	0·5	66·8	0·6	14	23	14	13
16-20	17·6			0·6	38·6			0·8	39·6	0·6	59·4	0·9	5	6	6	5
Feb. 10-15	26·0			0·5	85·9			0·8	56·4	0·5	90·9	0·9	7	6	3	6
16-23		1·8		0·6	12·0			0·3	21·2	0·6	24·7	0·5	5	4	8	6
Mar. 4-15	5·0			0·1	21·5		0·7		40·6	0·6	46·3	0·7	11	10	7	10
16-31		19·4		0·1		7·6	0·8		35·3	0·2	28·2	0·8	11	8	2	13
April 1-15		5·2	0·0		12·3		0·7		40·3	0·4	33·4	0·7	14	13	5	21
16-30		4·4	0·3		14·8		1·3		62·3	0·4	50·8	1·3	20	17	5	25
May 1-15	50·2		0·6		54 7		1·7		62·6	0·6	61·6	1·7	14	10	11	18
16-31		24·1	1·3		5·4		2·8		47·5	1·3	49·0	2·8	21	20	31	31
June 1-16		43·4	0 9			21·8	2·6		53·9	0·9	55·9	2·6	18	23	23	28
17-30																
July 3-7		20·4	0·9			0·8	2·8		24·6	0·9	30·8	2·8	3	3	8	8
18-31	0·9		0·2		29·5		1·1		35·7	0·3	64·7	1·1	12	20	2	22
Aug. 1-15		19·0		0·3	6·1		0·7		35·1	0·5	51·7	0·7	14	20	11	16
16-25	30·5			0·4	52·2			0·1	47·3	0·5	70·3	0·4	7	12	7	7
Sept. 1-13	21·5			0·4	31·9		0·1		57·0	0·5	55·7	0·5	20	18	11	8
17-30	7·9			0·2	25·2			0·0	48·8	0·4	55·2	0·5	16	20	6	12
Oct. 1-15	23·1			0·0	41·5		0·3		49·9	0·5	55·8	0·8	15	16	11	17
16-31	22·7			0·5	40·5			0·3	60·4	0·6	61·9	0·6	19	20	13	12
Nov. 1-15	16·7			0·2	42·6		0·2		45·0	0·4	56·7	0·6	13	16	6	12
16-30	7·2			0·2	38·2		0·0		48·6	0·7	64·4	0·9	21	23	16	22
Dec. 1-15		10·8		0·2	18·5		0·3		34·0	0·4	57·2	0·7	13	22	8	17
16-31		18·5		0·3	14·6		0·2		39·5	0·5	53·3	0·6	17	25	11	13
TOTALS...	229·3	169·0	4·2	4·9	616·6	30·2	16·3	2·5	1023·2	12·8	1244·7	23·7	310	355	225	342
MEANS ...	+ 2·5		− 0·0		+ 24·4		+ 0·6		42·6	0·5	51·9	1·0				

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

TABLE 6.—*Mean errors E_1 and E_3 for 1930.*

KARĀCHI

PERIOD 1930	MEAN ERRORS (Predicted – actual)												Numbe of errors		
	E₁*								E₂*				30 minutes of time		0· feet 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.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*			
	+	−	+	−	+	−	+	−							
Jan. 1-15		8·3	0·0			5·4	0·2		12·3	0·2	14·9	0·2	4	1	0
16-31	0·0			0·3		3·0	0·0		11·9	0·3	7·0	0·2	2	0	0
Feb. 1-15		2·7	0·1		1.6		0·4		12·5	0·2	14·1	0·4	2	5	0
16-28		3·8		0·4		3·2		0·2	18·0	0·4	12·1	0·2	4	3	0
Mar. 1-15		5·4		0·5	1·4			0·2	13·2	0·5	14·8	0·3	2	5	1
16-31		2·8		0·3		2·2		0·1	15·7	0·3	9·4	0·2	4	1	0
April 1-15		0·5		0·6	4·1			0·2	7·7	0·6	10·9	0·2	0	1	2
16-30		7·9		0·4		2·6		0·2	12·7	0·4	11·2	0·3	3	1	0
May 1-15		0·3		0·1		3·1	0·3		6·7	0·2	8·2	0·4	0	2	0
16-31		6·5	0·1		3·2		0·3		9·5	0·2	14·1	0·3	2	3	0
June 1-15		3·2		0·5		4·5		0·2	7·3	0·5	11·8	0·3	0	0	5
16-30		7·1		1·0		1·6		0·8	10·1	1·0	12·8	0·8	1	1	13
July 1-15		5·2		0·3		4·2		0·1	9·6	0·3	11·7	0·2	0	0	0
16-31		2·5		0·3	1·6			0·0	8·1	0·3	11·5	0·3	2	1	0
Aug. 1-15		2·4		0·0		2·9	0·2		9·6	0·1	9·7	0·3	2	0	0
16-31		3·2		0·4		0·3		0·1	10·1	0·4	8·7	0·2	1	1	0
Sep. 1-15		10·5		0·4		2·2		0·1	12·6	0·4	12·7	0·2	2	1	0
16-30	3·8			0·1	5·4		0·2		7·8	0·2	9·5	0·2	1	2	0
Oct. 1-15		13·6		0·2		4·2	0·1		15·7	0·2	10·1	0·1	5	1	0
16-31	1·5			0·4	2·3			0·2	9·8	0·4	12·4	0·2	4	4	1
Nov. 1-15		0·5		0·2	4·9		0·1		6·0	0·3	10·4	0·2	0	2	
16-30		3·1		0·4	1·2			0·3	7·2	0·4	10·9	0·3	0	2	
Dec. 1-15		2·4		0·4	5·7			0·2	6·4	0·5	8·7	0·3	1	0	
16-31		7·6		0·1		4·8		0·0	15·3	0·2	11·4	0·2	3	2	
TOTALS	5·3	99·5	0·2	7·3	31·4	44.2	1·8	2·9	255·8	8·5	269·0	6·5	45	39	2
MEANS …	− 3·9		− 0·3		− 0·5		− 0·0		10·7	0·4	11·2	0·3			

TABLE 7.—*Mean errors E_1 and E_2 for 1930.*

BHĀVNAGAR

PERIOD 1930	MEAN ERRORS (Predicted – actual)												Number of errors exceeding			
	E_1*								E_2*				*30 minutes* of time		*1·0 feet* of heigh	
	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	4·5		0·1			12·6	0·0		12·0	0·4	16·7	0·5	0	0	0	1
16-31	2·6			0·3		29·6		1·0	11·3	0·6	29·6	1·1	0	7	1	5
Feb. 1-15	3·8		0·5			27·7		0·1	13·3	0·6	31·9	1·3	0	8	2	7
16-28		1·6		0·3		24·2		0·8	6·4	0·4	25·1	1·1	0	4	0	5
Mar. 1-15	10·3			0·3		22·3		0·5	15·3	0·5	26·4	1·1	2	6	2	4
16-31	10·6			0·1		23·4		0·9	13·3	0·3	26·9	1·0	0	6	0	3
April 1-15	17·1			0·5		27·9		1·0	17·1	0·8	33·0	1·4	1	9	3	5
16-30	11·9			0·3		14·4		0·3	13·5	0·5	21·2	0·4	0	5	2	1
May 1-15	11·9			0·3		24·3		0·5	13·5	0·7	25·2	0·9	0	5	2	4
16-31	11·9		0·1			11·4	0·3		11·9	0·5	14·3	0·7	0	2	1	1
June 1-15	13·9			0·8		14·7	0·0		13·9	1·0	15·9	0·4	0	1	6	0
16-30	15·1			1·1		3·8		0·8	18·1	1·1	15·1	1·1	0	1	7	6
July 1-15	14·7			0·9		15·5	0·6		14·7	0·9	15·6	0·9	1	0	4	5
16-31	12·8			0·7		6·9		0·1	19·6	0·7	12·9	0·8	0	1	3	4
Aug. 1-15	9·5			0·7		6·9	1·0		13·7	0·8	9·3	1·0	0	0	4	8
16-31	10·8			0·4		1·9	0·5		13·4	0·5	13·7	1·1	0	2	4	4
Sep. 1-15	18·5			0·9	18·5			0·7	19·3	1·1	18·5	1·2	0	0	5	7
16-30	6·8		0·0		6·7			0·4	7·7	0·4	6·9	0·8	0	0	0	5
Oct. 1-15	6·8			0·3		1·0	0·2		9·7	0·5	10·2	0·7	0	0	1	2
16-31		2·3		0·6		2·9		0·8	7·0	1·1	7·8	1·3	0	0	7	7
Nov. 1-15	12·6			0·3		2·1	0·6		13·3	0·5	7·1	0·6	0	0	3	3
16-30	7·6			0·4		3·4		0·6	15·5	0·5	12·1	0·7	0	0	2	3
Dec. 1-15	8·5			0·3		11·2	0·0		17·0	0·6	12·1	0·2	0	0	3	0
16-31	10·2		0·1			7·4		0·3	15·7	0·7	12·4	0·6	2	0	4	1
TOTALS	232·4	3·9	0·8	9·5	25·2	295·5	3·2	8·8	326·2	15·7	419·9	20·9	6	57	66	91
MEANS ...	+ 9·5		− 0·4		− 11·3		− 0·2		13·6	0·7	17·5	0·9				

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

TABLE 8.—*Mean errors E_1 and E_2 for 1930.*

BOMBAY (APOLLO BANDAR)

PERIOD 1930	MEAN ERRORS (Predicted − actual)												Numbe errors e		
	E_1*								E_2*				30 minutes of time		
	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.	
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*			
	+	−	+	−	+	−	+	−							
Jan. 1-15		4·2		0·1		4·6	0·1		9·5	0·3	9·4	0·2	2	1	0
16-31		9·7	0·2			16·5	0·2		12·2	0·3	16·7	0·3	0	2	0
Feb. 1-15		8·5	0·4			12·1	0·5		11·1	0·4	16·5	0·5	0	5	0
16-28		12·9		0·1		17·1		0·1	13·0	0·1	20·3	0·3	2	2	0
Mar. 1-15		1·0		0·3		2·9		0·2	7·2	0·4	11·8	0·3	0	1	1
16-31		15·9		0·2		17·6		0·1	16·1	0·2	19·3	0·4	2	5	0
April 1-15		2·8		0·6		9·0		0·3	10·0	0·6	13·5	0·3	0	2	1
16-30	0·2			0·5		6·7		0·3	10·8	0·5	11·8	0·4	1	1	0
May 1-15	4·1			0·1	1·6		0·3		10·3	0·3	10·3	0·4	1	1	0
20-31		8·3	0·0			12·7	0·1		12·7	0·2	15·3	0·2	0	2	0
June 1-15		3·6		0·4		9·0		0·2	9·1	0·4	11·7	0·2	0	1	2
16-30		7·7		0·7		2·3		0·8	13·1	0·7	11·5	0·8	2	3	7
July 1-15	3·1			0·1	6·4			0·2	12·5	0·3	8·4	0·2	0	0	0
16-31		2·6		0·1	4·5			0·2	10·8	0·4	11·1	0·3	0	0	1
Aug. 1-15	7·0		0·4			0·6	0·0		14·9	0·4	8·3	0·2	4	1	1
16-31		6·3	0·0			3·5		0·1	11·0	0·3	14·6	0·2	1	2	0
Sept. 1-15		1·7	0·1			5·4		0·2	11·4	0·3	11·2	0·3	2	0	0
16-30		1·5	0·4			4·0	0·1		10·4	0·4	12·0	0·2	1	2	0
Oct. 1-11	3·0		0·2			0·7	0·0		3·5	0·3	3·2	0·3	0	1	0
17-31		12·7		0·1		13·3		0·1	15·0	0·2	13·6	0·3	4	4	1
Nov. 1-15		4·0	0·1			4·3	0·1		7·9	0·2	8·3	0·2	0	0	0
16-30		6·8		0·2		12·0		0·1	9·1	0·3	14·0	0·2	1	2	0
Dec. 1-15		2·0		0·2		9·0		0·0	7·4	0·3	9·2	0·2	0	1	0
16-31		10·0	0·1			10·2	0·1		12·2	0·3	11·7	0·3	3	3	[illegible]
TOTALS ..	17·4	122·2	1·9	3·7	12·5	173·5	1·5	2·9	261·2	8·1	293·7	7·2	26	42	14
MEANS ..	− 4·4		− 0·1		− 6·7		− 0·1		10·9	0·3	12·2	0·3			

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

TABLE 9.—*Mean errors E_1 and E_2 for 1930.*

COLOMBO

PERIOD 1930	MEAN ERRORS (Predicted—actual)												Number of errors exceeding			
	E_1*								E_2*				*30 minutes* of time		*0·3 feet* 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		18·5	0·0			20·0		0·0	19·7	0·1	21·1	0·1	6	6	0	0
16-31		48·4	0·1			37·7		0·1	48·4	0·2	37·7	0·1	19	15	4	1
Feb. 13-15	18·6		0·0		15·2		0·1		18·6	0·1	15·2	0·1	0	0	0	0
16-28	6·5			0·1	10·9			0·0	11·4	0·2	17·6	0·2	0	4	2	0
Mar. 1-15	17·4			0·2	10·7			0·1	18·2	0·2	12·8	0·2	3	1	4	0
16-31	17·1			0·2	17·6			0·0	17·1	0·2	20·1	0·1	3	2	3	0
April 1-15	21·1			0·3	16·5			0·2	21·1	0·3	20·3	0·2	4	5	13	4
16-30	23·9			0·3	20·3			0·1	26·2	0·3	21·0	0·1	9	8	4	0
May 1-15	13·8		0·1		10·4		0·2		14·8	0·2	16·9	0·2	1	2	5	7
16-31	4·4		0·1			3·4	0·1		15·7	0·2	14·0	0·2	3	4	4	4
June 1-15		9·1		0·1	0·0			0·1	15·0	0·2	12·8	0·1	3	1	5	3
16-30		1·4		0·3		13·5		0·2	14·3	0·3	19·2	0·2	2	4	5	7
July 1-15	5·2			0·1	9·3		0·0		19·7	0·1	13·6	0·1	4	0	0	0
16-31	10·7			0·2	6·3			0·1	15·5	0·2	14·7	0·2	4	1	7	6
Aug. 1-15	0·0			0·1		0·7	0·1		10·6	0·1	10·6	0·2	1	2	0	2
16-31		0·7		0·2	1·8			0·2	13·1	0·2	13·0	0·2	3	3	6	4
Sept. 1-15		1·6		0·2		6·8		0·0	31·9	0·2	33·0	0·2	10	9	7	5
16-30	15·3		0·1			0·2	0·2		15·8	0·1	17·1	0·2	4	3	0	1
Oct. 1-15	1.6		0·1		4·3		0·3		13·5	0·1	10·7	0·3	1	2	0	11
16-31	10·3			0·0	3·4		0·1		14·3	0·2	11·2	0·2	4	0	4	3
Nov. 1-15	14·6		0·0		14·0		0·2		16·8	0·1	14·9	0·2	2	4	0	4
16-30	18·9			0·3	14·8			0·1	22·9	0·3	16·0	0·2	4	2	12	6
Dec. 1-15	11·8			0·3	8·6			0·2	13·4	0·3	16·9	0·2	4	5	6	4
16-31	16·3			0·0	9·0		0·1		20·7	0·1	19·2	0·1	6	3	1	2
TOTALS	227·5	79·7	0·5	2·9	173·1	82·3	1·4	1·4	448·7	4·5	419·6	4·1	100	86	92	73
MEANS ...	+ 6·2		− 0·1		+ 3·8		0·0		18·7	0·2	17·5	0·2				

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

TABLE 10.—*Mean errors E_1 and E_2 for 1930.*

TRINCOMALEE

PERIOD 1930	MEAN ERRORS (Predicted—actual)												Number of errors exceed		
	E_1 *								E_2 *				30 minutes of time		
	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.	
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*			
	+	—	+	—	+	—	+	—							
Jan. 1-15	3·3			0·5		21·4		0·0	25·9	0·5	37·0	0·1	10	17	27
16-31	23·3		0·0		32·8			0·0	26·8	0·1	43·7	0·1	13	18	4
Feb. 1-15	11·6			0·2	1·9		0·0		31·4	0·3	28·0	0·2	16	15	14
16-28	9·9			0·5	40·8			0·4	23·7	0·5	41·5	0·4	8	17	23
Mar. 1-15	17·3			0·6		14·2		0·4	29·5	0·6	25·8	0·4	13	6	28
16-31	16·7			0·5	32·3			0·4	23·9	0·5	33·5	0·4	9	14	28
April 1-15	19·1			0·6	17·7			0·5	30·0	0·6	29·8	0·5	16	13	28
16-30	45·5			0·4	48·1			0·2	45·5	0·4	48·1	0·3	15	13	16
May 1-15	19·7			0·5	20·3			0·0	27·7	0·5	31·4	0·2	11	10	25
16-31	34·9			0·6	14·1			0·2	51·4	0·6	37·5	0·2	21	13	31
June 1-15	42·0			0·2	34·6			0·3	45·0	0·2	36·8	0·3	16	14	10
16-30	61·1			0·5	56·6			0·2	61·1	0·5	56·6	0·2	26	26	29
July 1-15	42·5			0·5	43·3			0·1	44·4	0·5	50·9	0·1	16	17	24
16-31	0·5			0·6	1·8			0·3	20·1	0·6	15·6	0·3	4	3	28
Aug. 1-15	1·1			0·7		4·6		0·1	25·6	0·7	15·4	0·1	11	3	30
16-31	9·8			0·6	19·0			0·5	48·0	0·6	35·2	0·5	15	12	29
Sept. 1-15		14·5		0·5		14·8		0·2	20·1	0·5	24·5	0·2	6	9	18
16-30		18·5		0·5		24·8		0·2	22·1	0·5	39·1	0·2	7	13	25
Oct. 1-15		4·0		0·3		7·9		0·0	29·7	0·3	31·0	0·1	12	13	19
16-31	24·3			0·4	32·3			0·1	27·0	0·4	34·4	0·3	9	10	25
Nov. 1-15		5·0		0·4		9·6		0·3	26·0	0·4	46·6	0·3	7	17	14
16-30	12·7			1·1	22·4			0·7	34·5	1·1	45·2	0·7	17	17	29
Dec. 1-15	31·4			0·6	27·2			0·1	39·2	0·6	27·7	0·2	16	11	28
16-31	40·1			0·3	35·2			0·1	43·9	0·3	37·8	0·1	16	13	16
TOTALS ...	466·8	42·0	0·0	11·6	480·4	97·3	0·0	5·3	802·5	11·8	853·1	6·4	310	314	548
MEANS ...	+ 17·7		− 0·5		+ 16·0		− 0·2		33·4	0·5	35·5	0·3			

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

TABLE 11.—*Mean errors E_1 and E_2 for 1930.*

MADRAS

PERIOD 1930	MEAN ERRORS (Predicted—actual)												Number of errors exceeding			
	E_1*								E_2*				30 *minutes* of time		0·4 *feet* 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	7·4		0·0		5·2		0·1		8·8	0·1	6·8	0·1	0	0	0	0
16-31	5·4		0·2		5·9		0·3		6·9	0·2	6·5	0·3	0	0	0	1
Feb. 1-15	10·9			0·1	8·8			0·1	11·3	0·2	9·6	0·2	0	0	0	0
16-28	4·7			0·5	5·4			0·4	7·5	0·5	7·4	0·4	0	0	12	6
Mar. 1-15	12·5			0·4	10·7			0·3	12·9	0·4	10·7	0·3	0	0	10	7
16-31	3·4			0·3	3·3			0·3	7·1	0·3	6·6	0·3	0	0	4	3
April 1-15	10·5			0·2	9·7			0·2	10·5	0·2	10·4	0·2	0	0	3	4
16-30	2·8		0·0		7·3		0·1		5·8	0·1	9·1	0·1	0	1	0	0
May 1-15	4·6			0·1	4·5		0·1		5·9	0·2	6·6	0·2	0	0	0	1
16-31	0·1			0·1	2·0			0·1	5·4	0·1	5·3	0·1	0	0	0	0
June 1-15	4·3		0·1		3·0		0·2		5·9	0·2	4·8	0·2	0	0	0	0
16-30	7.7		0·1		7·8		0·2		8·3	0·1	8·0	0·2	0	0	0	1
July 1-15	3·9		0·1		4·8		0·2		6·3	0·2	5·1	0·2	0	0	0	1
16-31	3·3			0·1	2·1			0·1	4·4	0·2	3·7	0·2	0	0	1	2
Aug. 1-15	5·5			0·2	6·5			0·1	6·9	0·2	6·6	0·2	0	0	0	0
16-31	0·3			0·3	0·0			0·3	4·1	0·3	4·6	0·3	0	0	3	3
Sept. 1-15	5·2		0·0		3·9		0·1		6·3	0·1	5·9	0·2	0	0	0	0
16-30	1·5		0·2		0·1		0·3		6·1	0·2	6·0	0·3	0	0	4	4
Oct. 1-15		2·9	0·2			2·2	0·3		6·5	0·2	6·8	0·3	1	1	3	8
16-31	4·2			0·2	5·4			0·1	6·7	0·2	8·1	0·2	0	1	5	0
Nov. 1-15	6·2			0·3	4·3			0·3	7·4	0·3	7·8	0·3	0	0	11	8
16-30		2·8		0·6		1·3		0·5	12·4	0·6	9·3	0·5	2	1	19	16
Dec. 1-15		6·4	0·0			8·5	0·0		9·6	0·3	11·2	0·2	0	0	2	3
16-31		12·9	0·0			12·3		0·0	14·2	0·2	12·3	0·2	0	0	0	0
TOTALS ...	104·4	25·0	0·9	3·4	100·7	24·3	1·9	2·8	187·2	5·6	179·2	5·7	3	4	77	68
MEANS ...	+ 3·3		− 0·1		+ 3·2		− 0·0		7·8	0·2	7·5	0·2				

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

TABLE 12.—*Mean errors E_1 and E_2 for 1930.*

KIDDERPORE

PERIOD 1930	MEAN ERRORS (Predicted − actual)											
	E₁*								E₂*			
	H. W. Time		H. W. Height		L. W. Time		L. W. Height		H. W. Time	H. W. Ht.	L. W. Time	L. W. Ht.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*
	+	−	+	−	+	−	+	−				
Jan. 1-15	5·0		0·2		4·2		0·4		13·3	0·2	7·4	0·5
16-31	14·7		0·1		11·0		0·6		15·7	0·4	17·0	0·7
Feb. 1-15	17·3		0·1		6·2		0·4		17·3	0·4	12·2	0·5
16-28	19·2			0·4	17·0		0·3		19·4	0·6	19·3	0·6
Mar. 1-15	15·5			0·2	8·3		0·2		15·5	0·4	12·2	0·4
16-31	10·4			0·5	3·4		0·0		13·4	0·7	13·9	0·5
April 1-15	8·4			0·1		4·4	0·3		12·0	0·6	12·2	0·5
16-30	2·2			0·3	3·2		0·2		12·8	0·4	10·6	0·3
May 1-15	10·1			0·7		7·9	0·3		15·4	0·8	12·8	0·5
16-31	19·7			0·6	16·4		0·0		20·5	0·7	18·1	0·3
June 1-15	6·2			0·1	1·1			0·0	13·4	0·3	12·8	0·4
16-30	8·5		0·1		7·5		0·3		11·7	0·3	10·4	0·4
July 1-15	2·0		0·7		9·2		0·9		13·3	0·9	13·4	1·0
16-31	10·8		0·0		5·4		0·7		12·5	0·5	13·2	0·8
Aug. 1-15	12·3			0·3	16·1		1·0		12·4	0·5	18·6	1·0
16-31	2·6		0·2			5·8	0·9		11·2	0·5	16·1	0·9
Sept. 1-15	2·5		0·8		8·0		1·6		14·1	0·8	11·1	1·6
16-30		1·6	0·8			2·6	1·8		11·5	1·1	12·3	1·8
Oct. 1-15		8·4	0·2			9·6	1·2		12·2	0·3	15·3	1·2
16-31		5·2	0·4			7·8	1·6		9·4	0·5	22·2	1·6
Nov. 1-15		7·4	0·1			10·1	1·1		9·7	0·5	12·2	1·1
16-30		1·0		0·8		4·4		0·0	9·2	0·8	13·5	0·5
Dec. 1-15		4·2		0·1		12·0	0·4		9·7	0·2	12·4	0·4
16-31	4·7			0·2	8·7		0·1		13·7	0·4	13·0	0·5
TOTALS	172·1	27·8	3·7	4·3	125·7	64·6	14·3	0·0	319·3	12·8	332·2	18·0
MEANS	+ 6·0		− 0·0		+ 2·5		+ 0·6		13·3	0·5	13·8	0·8

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

TABLE 13.—*Mean errors E_1 and E_2 for 1930.*

CHITTAGONG

PERIOD 1930	MEAN ERRORS (Predicted − actual)												Number of errors exceeding			
	E_1*								E_2*				*30 minutes* of time		*1·0 feet* 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	9·1		0·1		7·4		0·2		9·1	0·1	7·9	0·4	0	0	0	0
16-31	8·7		0·0		8·9			0·0	10·6	0·5	9·3	0·4	0	0	0	1
Feb. 1-15	9·8		0·0		5·3		0·0		9·8	0·2	5·6	0·5	0	0	0	2
16-28	3·8			0·1	2·5		0·0		4·5	0·4	5·2	0·2	0	0	0	0
Mar. 1-15	5·3			0·1	4·1			0·1	7·2	0·5	5·9	0·2	0	0	2	0
16-31	3·7			0·1	3·1			0·0	4·7	0·7	5·5	0·3	0	0	5	0
April 1-15	15·3		0·4		13·7		0·6		16·3	0·9	14·5	0·6	3	0	6	3
16-30	16·7		0·6		15·1		0·3		17·3	0·6	15·1	0·6	2	1	3	3
May 1-15	1·2		0·2		7·8		0·1		7·2	0·5	10·7	0·5	0	1	0	1
16-31	2·1		0·2		9·5		0·4		8·2	0·4	9·6	0·4	0	0	0	1
June 1-15	5·8		0·1		7·0			0·1	11·1	0·7	13·9	0·3	0	1	2	0
16-30	10·3			0·0	11·1			0·3	13·1	0·4	15·5	0·4	0	0	0	1
July 1-15	10·9			0·3	10·9			0·1	13·1	0·4	14·3	0·7	0	0	0	4
16-31	10·1		0·4		17·8		0·3		10·3	0·8	19·3	0·5	1	5	5	0
Aug. 1-15	3·3			0·1	10·9			0·0	9·7	0·3	10·9	0·5	0	0	0	0
16-31	5·2		0·3		5·6		0·2		8·7	0·5	7·1	0·3	0	0	2	1
Sept. 1-15	5·7		0·2		4·0		0·5		6·0	0·7	5·1	0·6	0	0	4	3
16-30	6·0			0·2	7·6			0·6	7·6	0·4	7·6	0·6	0	0	1	4
Oct. 1-15	4·6		0·0		3·3		0·1		5·4	0·4	4·3	0·6	0	0	0	1
16-31	2·5		0·2		0·4		0·0		3·3	0·3	3·5	0·4	0	0	1	0
Nov. 1-15	3·5			0·3	1·5			0·1	4·5	0·4	3·5	0·3	0	0	2	0
16-30	5·5			0·3	3·8			0·5	6·3	0·5	6·1	0·6	0	0	3	4
Dec. 1-15	3·5		0·1		2·2		0·0		4·8	0·1	5·1	0·2	0	0	0	0
16-31	3·3			0·1	1·2			0·1	6·4	0·3	6·3	0·2	0	0	0	0
TOTALS ...	155·9		2·8	1·6	164·7		2·7	1·9	205·2	11·0	211·8	10·3	6	8	36	29
MEANS ...	+ 6·5		+ 0·1		+ 6·9		+ 0·0		8·6	0·5	8·8	0·4				

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

TABLE 14.—*Mean errors E_1 and E_2 for 1930.*

AKYAB

PERIOD 1930	MEAN ERRORS (Predicted – actual)														Number errors	
	E_1*								E_2*						30 minutes of time	
	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.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*				
	+	–	+	–	+	–	+	–								
Jan. 1-15	6·5		0·2		5·6		0·3		6·5	0·2	5·6	0·3			0	0
16-31	6·8		0·2		6·1		0·5		6·8	0·3	6·1	0·5			0	0
Feb. 1-15	6·3		0·3		5·9		0·1		6·3	0·3	5·9	0·2			0	0
16-28	6·2			0·2	5·8		0·2		6·2	0·4	5·8	0·2			0	0
Mar. 1-15	6·7			0·2	5·7		0·0		6·7	0·3	5·7	0·2			0	0
16-31	5·9			0·3	6·1			0·2	5·9	0·3	6·1	0·2			0	0
April 1-15	6·6			0·2	5·7			0·2	6·6	0·3	5·7	0·2			0	0
16-30	6·1		0·1		5·5		0·1		6·1	0·3	5·5	0·2			0	0
May 1-15	6·1			0·2	5·6			0·0	6·1	0·2	5·6	0·3			0	0
16-31	5·7			0·0	5·9			0·1	5·7	0·1	5·9	0·2			0	0
June 1-15	6·1			0·1	4·4		0·1		6·1	0·2	4·4	0·2			0	0
16-30	5·6			0·1	5·2			0·1	5·6	0·3	5·2	0·1			0	0
July 1-15	5·3			0·1	5·9			0·1	5·3	0·2	5·9	0·2			0	0
16-31	7·1		0·1		5·6		0·0		7·1	0·4	5·6	0·1			0	0
Aug. 1-15	6·4			0·3	5·9			0·3	6·4	0·3	5·9	0·3			0	0
16-31	6·3		0·1		5·4			0·1	6·3	0·2	5·4	0·2			0	0
Sept. 1-15	5·8		0·3		6·2		0·4		5·8	0·3	6·2	0·4			0	0
16-30	6·2			0·1	6·7			0·1	6·2	0·2	6·7	0·3			0	0
Oct. 1-15	6·2		0·2		5·4		0·1		6·2	0·2	5·4	0·4			0	0
16-31	6·2			0·0	5·8		0·1		6·2	0·3	5·8	0·2			0	0
Nov. 1-15	5·5			0·4	4·8			0·4	5·5	0·5	4·8	0·5			0	0
16-30	6·1			0·5	5·7			0·3	6·1	0·6	5·7	0·4			0	0
Dec. 1-15	5·9		0·0		5·0		0·2		5·9	0·1	5·0	0·3			0	0
16-31	5·6			0·4	5·7			0·1	5·6	0·4	5·7	0·4			0	0
TOTALS	147·2		1·5	3·1	135·6		2·1	2·0	147·2	6·9	135·6	6·5			0	0
MEANS	+ 6·1		– 0·1		+ 5·7		+ 0·0		6·1	0·3	5·7	0·3				

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

TABLE 15.—*Mean errors E_1 and E_2 for 1930.*

ELEPHANT POINT (PILAKĀT CREEK)

PERIOD 1930	MEAN ERRORS (Predicted—actual)												Number of errors exceeding			
	E_1*								E_2*				30 *minutes* of time		1·0 *feet* of height	
	H. W. Time *minutes*		H. W. Height *feet*		L. W. Time *minutes*		L. W. Height *feet*		H. W. Time *minutes*	H. W. Ht. *feet*	L. W. Time *minutes*	L. W. Ht. *feet*	H. W.	L. W.	H. W.	L. W.
	+	—	+	—	+	—	+	—								
Jan. 1-15	28·1			0·3	17·3		0·5		28·1	0·5	18·1	0·6	13	6	3	3
16-31	29·0			0·2	23·7		0·5		29·0	0·6	24·0	0·6	12	10	3	4
Feb. 1-15	38·1			0·2	29·6		0·1		38·1	0·4	29·6	0·3	22	15	2	1
16-28	34·2			0·1	31·9		0·2		35·2	0·4	31·9	0·6	17	15	2	4
Mar. 1-15	41·6			0·3	29·3		0·1		41·6	0·4	29·3	0·5	23	14	1	0
16-31	26·9			0·6	23·5			0·2	30·3	0·7	24·0	0·4	18	6	8	1
April 1-15	29·2			0·4	18·2			0·0	29·2	0·4	18·6	0·4	14	3	0	0
16-30	34·1			0·3	31·7		0·3		34·8	0·3	31·7	0·6	20	13	0	4
May 1-15	26·5			0·4	19·5		0·1		26·5	0·5	19·7	0·5	12	6	2	1
16-31	28·7			0·6	24·1			0·3	28·7	0·6	24·3	0·5	11	9	4	2
June 1-15	23·9			0·1	15·3		0·2		23·9	0·4	15·6	0·6	6	5	3	6
16-30	26·3			0·2	18·2			0·2	26·3	0·4	18·2	0·4	8	2	0	2
July 1-15	10·4			0·2	11·1		0·4		12·0	0·3	14·5	0·7	0	3	0	7
16-31	30·5			0·1	16·1			0·1	30·5	0·3	16·4	0·4	13	4	0	0
Aug. 1-15	18·8			0·7	17·2		0·0		19·1	0·7	18·0	0·4	4	3	8	1
• 16-31	16·6		0·1		5·6			0·0	17·1	0·4	12·4	0·4	4	0	1	0
Sept. 1-15	11·5			0·2	7·9		0·5		14·1	0·4	11·0	0·6	1	1	2	3
16-30	15·0			0·0	3·7			0·2	17·1	0·3	10·4	0·6	3	0	0	5
Oct. 1-15	5·9			0·2		1·9	0·5		12·1	0·2	7·2	0·6	2	0	0	5
16-31	3·4			0·2		7·0		0·0	8·6	0·2	12·9	0·5	1	0	0	6
Nov. 1-15	1·3			0·8		11·2		0·3	6·6	0·8	11·4	0·4	0	0	7	0
16-30	5·1			0·4		7·0		0·2	6·1	0·5	12·1	0·6	0	0	1	6
Dec. 1-15	4·3			0·4		10·7	0·1		5·4	0·5	12·7	0·3	0	2	1	0
16-31	22·6			0·6		0·9	0·1		22·6	0·7	14·8	0·4	9	3	7	3
TOTALS ..	512·0		0·1	7·5	343·9	38·7	3·6	1·5	543·0	10·9	438·8	11·9	213	120	55	64
MEANS ..	+ 21·3		— 0·3		+ 12·7		+ 0·1		22·6	0·5	18·3	0·5				

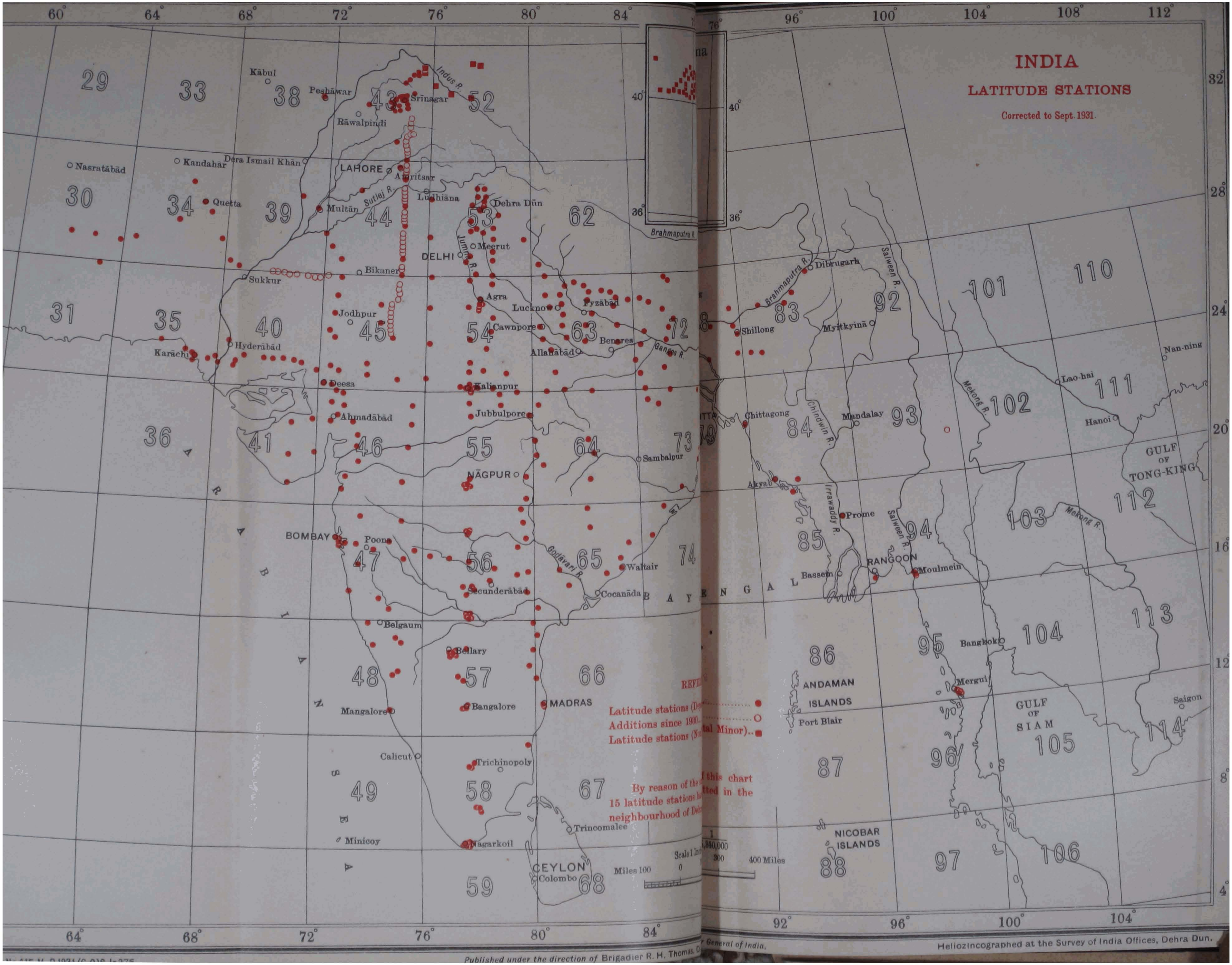
* E_1 is with regard to sign : E_2 is without regard to sign.

TABLE 16.—*Mean errors E_1 and E_2 for 1930.*

RANGOON

PERIOD 1930	MEAN ERRORS (Predicted – actual)												Number of errors exceeding		
	E_1*								E_2*				*30 minutes* of time		*1·0 feet 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.
	minutes		*feet*		*minutes*		*feet*		*minutes*	*feet*	*minutes*	*feet*			
	+	–	+	–	+	–	+	–							
Jan. 1-15		1·0	0·1		0·9		0·5		7·0	0·3	14·8	0·6	0	0	1
16-31		9·3	0·2			4·3	0·3		10·0	0·6	14·6	0·5	0	0	5
Feb. 1-15		4·3	0·2			1·0		0·0	7·5	0·4	13·0	0·5	0	0	3
16-28		7·4	0·2			2·6		0·1	9·8	0·4	11·8	0·5	2	0	2
Mar. 1-15		9·5	0·2			5·6		0·0	10·6	0·3	10·3	0·4	1	2	2
16-31		4·4		0·2	4·6			0·5	9·6	0·6	11·7	0·6	2	3	4
April 1-15		3·9	0·2			1·1		0·2	4·5	0·3	10·1	0·5	0	0	0
16-30		4·9	0·2		5·7		0·1		9·6	0·2	10·2	0·6	2	2	0
May. 1-15		5·2		0·1		5·2		0·1	6·1	0·4	13·5	0·6	0	0	0
16-31	2·0			0·5	7·5			0·5	9·9	0·5	13·2	0·7	2	3	2
June 1-15		3·8	0·1			2·6	0·3		7·1	0·3	14·3	0·6	0	0	0
16-30	2·9			0·1	6·3			0·2	8·8	0·3	12·6	0·5	1	0	0
July. 1-15	1·1			0·1	4·0			0·1	7·4	0·4	15·6	0·6	0	2	0
16-31	5·6		0·1		2·4			0·4	10·2	0·3	13·8	0·5	0	1	0
Aug. 1-15		8·4		0·6	5·7			0·2	13·5	0·6	14·1	0·4	1	0	6
16-31		1·2	0·2			0·6		0·1	9·0	0·5	11·4	0·4	0	0	2
Sept. 1-15		9·0	0·2		8·6		0·9		10·1	0·4	9·1	0·9	1	1	1
16-30	3·4		0·3		6·4		0·2		9·8	0·4	11·9	0·5	0	1	1
Oct. 1-15	3·2		0·4		6·4		1·0		7·7	0·5	8·6	1·0	0	0	3
16-31	1·2		0·5		3·7		0·5		7·7	0·5	12·4	0·6	1	2	1
Nov. 1-15	3·7			0·1	4·2		0·5		6·8	0·2	9·0	0·5	0	0	0
16-30	7·0		0·2		7·1		0·3		8·5	0·3	16·9	0·6	2	4	2
Dec. 1-15	0·5		0·1			1·3	0·6		6·1	0·3	13·0	0·6	0	0	0
16-31	2·7			0·1	8·9		0·5		7·1	0·4	16·4	0·6	0	1	1
TOTALS	33·3	75·3	3·4	1·8	82·4	24·3	5·7	2·4	204·4	9·4	302·3	13·8	15	22	36
MEANS ...	– 1·8		+ 0·1		+ 2·4		+ 0·1		8·5	0·4	12·6	0·6			

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



INDIA
LATITUDE STATIONS

Corrected to Sept. 1931.

REFE

Latitude stations (De ●
Additions since 1930 ○
Latitude stations (N tal Minor).. ■

By reason of the f this chart 15 latitude stations h tted in the neighbourhood of Deh

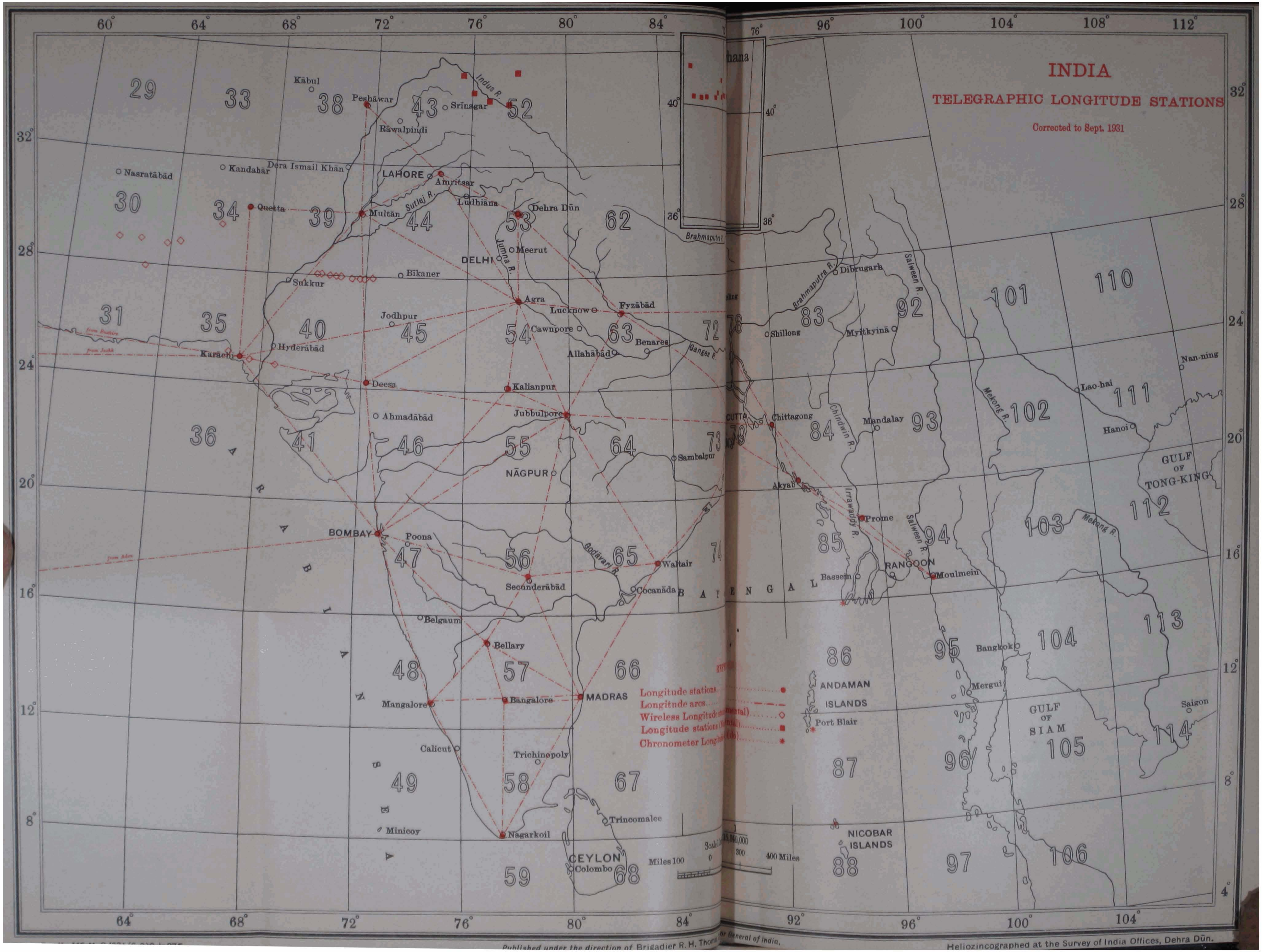
Published under the direction of Brigadier R. H. Thomas, D General of India.

Heliozincographed at the Survey of India Offices, Dehra Dun.

INDIA

TELEGRAPHIC LONGITUDE STATIONS

Corrected to Sept. 1931



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CHAPTER IV

DEVIATION OF THE VERTICAL

SECTION I

Latitude Detachment

BY CAPTAIN G. BOMFORD, R.E.

1. **Summary.**—A detachment under Mr. R. B. Mathur, B.A., undertook the observation of astronomical latitudes at 44 stations lying at intervals of about 10 miles along the meridian 75° E., between Ajmer (latitude 26° N.) and the Banihāl Pass (latitude 33° 30′ N.). Combining these observations with those of Major Glennie's 1925 season in Kashmīr, and with two stations of the De Filippi expedition, we now have an accurate geoidal section from the crest of Sir S. G. Burrard's "Hidden Range" in the south, through the area of deficiency at the foot of the Punjab hills, through the Pīr Panjāl, Srīnagar Valley and Great Himālaya, almost to the south edge of the Kara-koram.

2. **Programme.**—Between latitudes 28° and 32° 30′ observations were made at all the stations on the eastern flank of the Gurhāgarh Meridional Series, except at 6 stations where latitude had been observed previously. This part of the series consists of short sides (about 10 miles), and the spacing of the stations is well suited to the object in view. At the south end of the work, where the series enters more hilly country, it was necessary to observe at one or two extra stations between each pair of G.T. stations. These stations were fixed by resection from stations and points of modern topographical triangulation. Between latitude 32° 30′ and the Banihāl Pass, it was also convenient to place the astronomical stations near the Banihāl motor road, and to fix them by resection from surrounding topographical data.

Since only the meridional component of the deflection was being observed, it was necessary to align the stations as closely as possible along one meridian. In the central part this alignment was strictly followed, but some departures were inevitable at the two ends. The general alignment is, however, as nearly meridional as could well be hoped for.

When deciding on the programme of observations it was considered that a large number of comparatively low class observations were much preferable to a lesser number of the highest accuracy. To be undoubtedly correct within 1 second was considered to represent perfection, since when stations are only 10 miles apart this represents an error of only 3 inches in their relative geoidal height, and occasional (casual) errors of 2 seconds were not considered serious. So far as the astronomical observations go, the one-second standard has probably been achieved, since only two stations show a probable error of as much as $\pm 0''\cdot 4$, but the fixing of the geodetic position by resection proved troublesome in some places, and it is possible that a few errors of 2 seconds in the deflection may have resulted from this cause.

3. Astronomical observations.—The instrument used was the small Zenith Telescope, on a portable iron stand. This instrument was made by Troughton & Simms in about 1890. Its focal length is 30 inches, the diameter of its object glass is 2½ inches, and it is provided with two bubbles of sensitivity $2''\cdot 0$ to one-tenth of an inch It is illustrated in G.T.S. Volume XVIII, Plates 1, 2 & 3.

The observations were made by Mr. R. B. Mathur throughout. The programme was to observe about 8 pairs of latitude stars and 1 or 2 deviation stars on each of two nights at each station, which in fine weather represents about 7 hours work in all.

The use of the portable stand saved the necessity for an advance party for building brick pillars. For setting in azimuth, instead of using the meridian mark usually laid out by the advance party, the instrument was set by an observation to Polaris before observations began. A setting from Polaris was made correct to $5'$ (minutes) or less without difficulty, and was checked by comparing the times of transit of the first pair of zenith stars. For obtaining the required accuracy an azimuth error of $5'$ is negligible, provided the stops are so set that the deviation is the same in both positions of the instrument.

The value of the micrometer screw was determined before and after the season, and occasional check values have been obtained by solution from the discrepancies between values of latitude as obtained from different star pairs at one station. The values obtained have been satisfactorily constant, and one value has been accepted throughout. The north and south stars in the programme have been kept sufficiently well "balanced" to ensure that no serious doubt can arise from possible error in the micrometer value.

The discrepancy between the first and second night's observations at each station, and the probable error as deduced from the accordance of different star pairs, are given in Table 1, page 51.

4. Geodetic fixing.—In the central part of the work (32 stations) the astronomical station was in the immediate vicinity of a G.T. Station* and the geodetic latitude was determined without

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* Except at Makhu Purāna. where the G.T. station has been destroyed. The position of the Latitude station was here determined by plane-table fixing on a modern 1-inch map.

TABLE 1.—*Latitude Observations. Zenith Telescope, 1930-31.*

Station	Height	Longitude	Astronomical Latitudes					Geodetic Latitudes		
			1st night	2nd night	Diff.	p. e.	Resection	P. T.	Accepted §
	feet	° ′	° ′ ″	° ′ ″	″		° ′ ″	° ′ ″	° ′ ″
Banihāl Pass ...	9200	75 13	33 30 17·92	33 30 16·11	1·81	±0·33	33 30 27·5*	33 30 29	33 30 28·2
Nachilani ...	5000	11	21 22·32	21 21·95	0·37	0·17	21 54·3	21 52	33 21 53·2
Rāmban ...	2400	15	13 39·73	13 39·41	0·32	0·25	14 12·7†	14 13	33 14 12·7
Chineni ...	4000	17	01 57·38	01 57·74	0·36	0·19	02 33·4*	02 31	33 02 32·2
Dramthal ...	3800	15	33 00 47·80	33 00 47·90	0·10	0·28	33 01 23·7*	33 01 20	33 01 21·8
Udhampur ...	2500	08	32 55 16·81	32 55 16·22	0·59	0·16	32 55 51·6*	32 55 52	32 55 51·8
Suruin Sar ...	2100	03	45 38·73	45 38·39	0·34	0·23	32 46 02·6*	32 46 04	32 46 03·3
Gurhāgarh H.S. ...	2031	02	37 41·37	37 41·91	0·54	0·18			32 37 59·94
Bhūru-Chak T.S. ...	1053	07	26 41·67	26 43·14	1·47	0·32			32 26 55·89
Atalgarh T.S. ...	943	06	18 38·14	18 37·33	0·81	0·30			32 18 44·84
Mailu-Sailu T.S. ...	856	04	32 10 36·86	32 10 37·07	0·21	0·15			32 10 40·06
Siri T.S. ...	846	05	31 52 37·56	31 52 37·84	0·28	0·14			31 52 36·14
Chowinda T.S. ...	833	03	43 16·48	43 16·56	0·08	0·14			31 43 13·72
Dhīri-kot T.S. ...	789	03	34 56·73	34 56·44	0·26	0·15			31 34 53·52
Kalla T.S. ...	784	02	26 10·84	26 10·63	0·21	0·23			31 26 08·72
Makhu Purāna ...	687	00	31 06 46·11	31 06 46·37	0·26	0·17	...	31 06 49	31 06 49
Dalūwāla T.S. ...	728	03	30 59 05·62	30 59 05·25	0·37	0·20			30 59 06·89
Daraoli T.S. ...	759	03	...	48 35·61	...	0·14			30 48 36·17
Kunandwāla T.S. ...	745	02	30 39 39·26	39 37·68	1·58	0·40			30 39 37·85
Lakarwāla T.S. ...	736	02	30 35·62	30 34·83	0·79	0·20			30 30 33·92
Maihna S. ...	730	00	13 10·01	13 10·01	0·00	0·15			30 13 11·64
Kaila-Vāndar T.S. ...	727	75 00	30 03 45·35	30 03 45·17	0·18	0·18			30 03 48·27
Gar-Wāli T.S. ...	717	74 59	29 55 52·33	29 55 52·19	0·14	0·14			29 55 53·39
Tiloka T.S. ...	710	75 02	49 01·85	49 00·62	1·23	0·29			29 49 03·00
Sirsa S ...	738	75 01	31 34·34	31 33·60	0·74	0·17			29 31 35·39
Bānka S. ...	710	74 58	22 41·73	22 42·14	0·41	0·15			29 22 43·51
Rāmgarh S. ...	694	74 59	...	13 03·73	...	0·33			29 13 04·50
Siai S. ...	760	75 02	29 01 02·82	29 01 02·69	0·13	0·19			29 01 02·80
Rangarri S. ...	777	74 59	28 53 26·37	28 53 28·68	2·31	0·35			28 53 26·45
Mākar Thal S. ...	830	75 02	41 16·52	41 16·71	0·19	0·16			28 41 17·23
Randālia S. ...	1038	02	18 04·72	18 05·12	0·40	0·17			28 18 05·45
Gūgla-Bhar S. ...	1112	75 01	28 07 16·45	28 07 16·24	0·21	0·16			28 07 17·51
Bhūmba S. ...	1261	74 56	...	27 46 37·33	...	0·27			27 46 41·78
Maira Dās S. ...	1317	74 54	27 35 58·24	35 57·77	0·47	0·23			27 35 59·45
Shami Village ...	1600	75 01	...	26 07·37	...	0·28			27 26 06·20
Pānchwa H.S. ...	2048	74 56	27 13 30·45	...	...	0·24			27 13 29·56
Jāsri Village ...	1300	46	...	27 04 36·15	...	0·24	27 04 32·3†	27 04 29‡	27 04 32·30
Kinsirra H.S. ...	2423	42	26 54 30·46	...	...	0·15			26 54 25·39
Kharkari Village ...	1450	42	44 40·08	26 44 39·27	0·81	0·24	26 44 37·6*	26 44 37·2	26 44 37·40
Narwar Village ...	1500	42	36 11·26	26 36 11·33	0·07	0·16	26 36 10·6*	26 36 08·1	26 36 09·5
Gūdha H.S. ...	2418	46	28 08·55	...	...	0·33			26 28 09·92
Asapura Village ...	1500	47	19 49·67	26 19 49·90	0·23	0·16	26 19 55·3†	26 19 55‡	26 19 55·3
Shokli Village ...	1300	50	12 49·25	26 12 48·86	0·39	0·16	26 12 55·8†	26 12 56‡	26 12 55·8
Bupki H.S. ...	1878	74 49	26 03 50·16	...	...	±0·44			26 03 55·43

* Resection liable to 2″ or 3″ error.

† Resection apparently good to one second.

‡ From old 1-inch map.

§ Where there are no entries in the two preceding columns, the Latitude station is in the immediate vicinity of a G. T. Station.

difficulty. At the remaining stations the geodetic fixing was made by theodolite resection from topo. triangulation data and also by plane-table resection from the 1-inch map.

The accuracy of the theodolite resection proved disappointing. The necessary accuracy of angular measurement can of course be obtained without any difficulty even when using the most primitive theodolite, but the identification of old, unvisited, trig. points is not easy. This is especially so in the case of hills viewed from a deep valley. Half a dozen or more points were generally observed, as well as a Polaris or Sun azimuth, and it is apparent from the discordance of the rays (when computed semi-graphically) that in many cases the accepted position is liable to an error of 2″ of latitude. On the other hand, when the plane-table resection is based on several independent pieces of conspicuous detail shown on a modern 1-inch map, it is thought that the error of fixing is unlikely to exceed 2″, and where the theodolite fixing is clearly liable to 2″ error, the mean of the two values has been accepted, as shown in Table 1.

The question of geodetic fixing by resection is one of great importance from the point of view of furthering the rapid and inexpensive observation of sections of the geoid. Except in flat country, stations of the primary triangulation are generally the least accessible points of the district in which they lie, and they are generally placed too far apart for the deflection at their sites to be considered typical of the intervening country. Recourse to minor triangulation is therefore imperative: nor is it objectionable, since an error of less than 1 second (100 feet) represents perfection, and occasional (casual) errors of 200 or even 300 feet do not really matter. It is, however, often inconvenient to carry the camp and equipment even to the nearest minor triangulation station or point. The ideal at which to aim is that the detachment should move along a main road (preferably by motor car), halting for a day and two nights, or even less, at whatever intervals may prove most suitable for the work in hand. If coolies have to be engaged and camp moved to a hill top some miles from the road, a day or two will be wasted at each station, and progress will be halved.

The difficulty of resection from trig. points was foreseen, and this season's work has shown that it is not easily overcome, although the agreement with the plane-table fixings is sufficiently good to show that results based on either would not have been very seriously wrong. It was hoped that by taking special care with the trig. resection, it would have been possible to prove the accuracy of the plane-table resections for future years, but this has not been fully achieved. In the four cases where the former is really reliable, the discrepancy has been trivial in three cases, and 3″·3 in the fourth (Jusri). In this last case, the plane-table resection was based on an old map, which is not a fair test. Unfortunately two of the favourable cases are also based on old maps, and so must perhaps be attributed to chance. There is only one case in which a good trig. resection is associated with a new map, and the error is there 0″·3, which is good. But there is no case, except Jusri and perhaps Dramthal, where the trig. resection is not liable to as much error as the discrepancy between the two methods, and some confidence is felt in the probability of good geoidal sections being obtained from plane-table resections only.

5. Narrative of season's work.—The detachment, consisting of Mr. R. B. Mathur, one recorder and ten khalāsis, left Dehra Dūn on 27th Oct., and started work at the Banihāl Pass on 2nd Nov., whence they worked continuously from north to south completing work at Bupki H.S. on 9th March, and reaching Dehra on 11th March. Inconvenience, and a certain amount of delay, was caused by clouds, but it was very seldom that the full programme could not be completed in three nights. On these occasions a reduced programme was accepted. Snow and cold caused much discomfort in the Banihāl Pass, and water was poor and scanty in the part of the work which lay in Rājputāna. Various forms of transport were employed: motor lorries, mules and coolies on the Banihāl road: country carts in the Punjab and Ajmer : and permanent camel transport in Rājputāna and parts of the Punjab.

The normal routine was to march in the early morning, reaching the next station soon after midday. The instrument was then set up and the geodetic fixing carried out, when necessary, including the Polaris azimuth at dusk. Observations were made that night, which were computed the next day, when the programme for the next station was also prepared. The second night's observation followed, and camp was broken on the morning of the third day. With inexhaustible personnel, perfect weather and no transport difficulties, it would be possible to observe 15 stations a month on this system. Actually Mr. Mathur observed 12 stations in January and maintained an average of 10 stations a month.

The total cost of the detachment (excluding provision for instruments and administrative supervision) was Rs. 9,000 during the field season, to which may be added about Rs. 2,000 for computation in recess, a total cost of Rs. 250 per station, a result which is very creditable to Mr. Mathur.

6. Computations.—At each station one night's work was computed in the field to make sure that all was well before leaving the station. Where trig. resections were required, they also were computed in the field. In recess the astronomical computations were completed, the field computations were checked, and the Hayford anomalies were computed.

The preparation of the star programmes at so many field stations entailed quite a considerable amount of labour, which was lessened by a simple device which Mr. Mathur improvised. All suitable stars of the Greenwich catalogue are plotted by R. A. and declination on a long strip of squared transparent cloth (1 cm. = 1 of δ or 10^m of R. A.). In order to prepare the programme at any station, the chart is folded along the declination line corresponding to stars which pass through the zenith at the latitude concerned. The chart is then held up to the light, and pairs with suitably similar zenith distances and R. A's. can be immediately selected. This device was particularly useful when clouds caused interruption in the programme previously prepared : changes in the programme could be made at a moment's notice.

A statement of results, in the form of an addendum to the Supplement to Geodetic Report Vol. VI (list of all Indian deflection stations) is given in Table 4 (pages 68 to 73), at the end of this chapter.

7. The geoidal section.—Table 2 (pages 58 to 59) shows the values of the deflection found at this season's stations, and at older stations along the same line. The table also shows the deflections referred to the International Spheroid *.

In Plate VI, these deflections are integrated up to form a section of the geoid. The line of section is the meridian 75° E. from latitude 26° to latitude 34° 35′ (near Churawan. See Geodetic Report Vol. III, Plate VIII), whence the section line turns north-east to Skārdu. In the flat country south of latitude 33°, stations which do not lie exactly on the section line have been assumed to lie on it at their true latitudes, but in the hills stations off the line have been projected on to it in a direction parallel to the general trend of the Himālayas. In the small part of the section north of latitude 34° 35′, where it does not run north and south, the total deflection has been assumed to lie at right angles to the hills, and the observed meridional deflections have consequently been (rather doubtfully) multiplied by 1·3 to give their components along the section.

The Hayford anomalies have similarly been integrated up to give the section of the compensated geoid, see Plate VI. The plate also shows the section of the Survey of India No. II spheroid†, placed in position relative to the International spheroid, so that the relations of the geoid and compensated geoid to this spheroid are also shown. For further comparison the plate includes a section showing the average height of the country, and a curve of $g - \gamma c$, the Hayford gravity anomaly. This curve is produced from the contours given on Chart XII, except north of the Srīnagar Valley, where the values given are those at stations on the section line. Reference to Chart XII shows that outside Kashmīr the gravity data are rather scanty, and this curve only shows the variation of gravity in a generalised manner.

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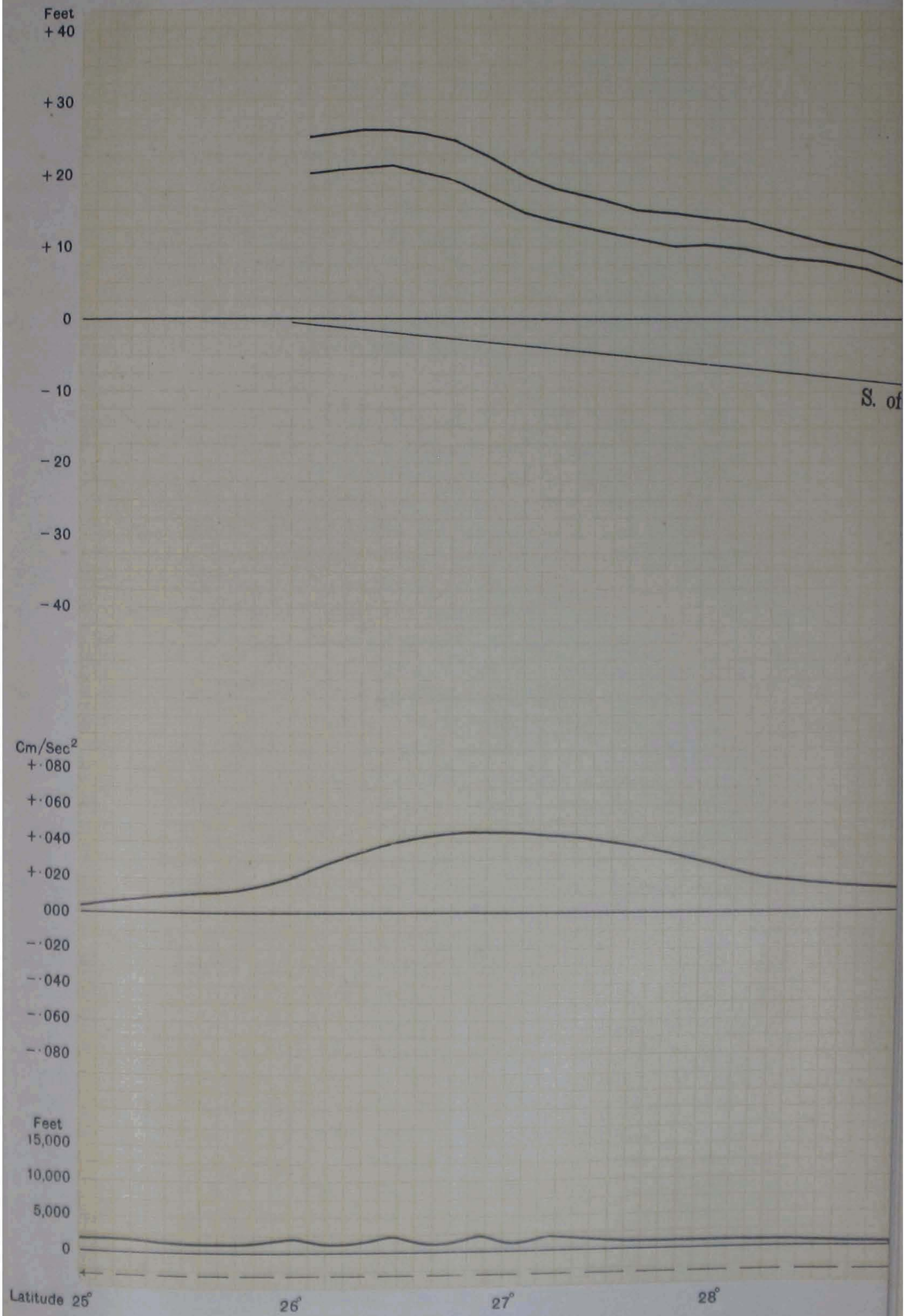
* With such deflections at the origin as produce the best fit between it and the Indian Compensated Geoid.

† $a = 6{,}378{,}541$ metres, $1/\epsilon = 292{\cdot}4$. Deflections at origin 1″·98 S. and 2″·81 W.



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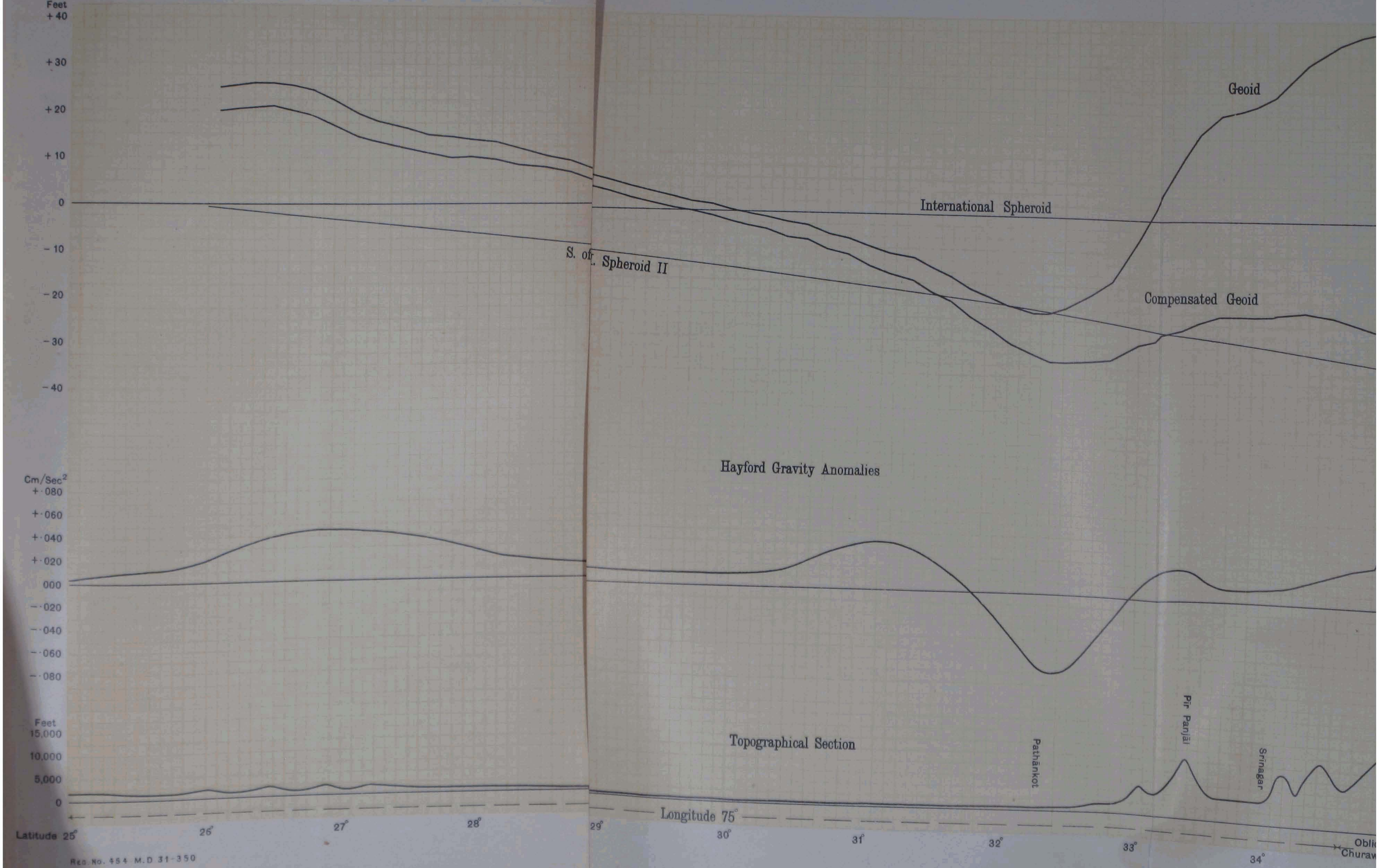
GEOIDAL SECTION MERIDIAN 75° E



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The datum heights of the geoidal sections above the International spheroid at the south end have been so chosen as to make the southerly 200 or 300 miles agree as closely as possible with the geoidal contours published in Geodetic Report Vol. V, Charts X and XII.

The form of the compensated geoid calls for comment in some respects. It is noticeable that the fall between lats. 26° and 31° agrees closely with that shown in Geodetic Report Vol. V, Chart XII (32 feet compared with 33[*]). It had been expected that the previous paucity of observations in the Punjab might have led to some inaccuracy there, since the steady fall to the north appeared rather incompatible with the predominantly positive gravity anomalies obtained over most of the northern part of the area, but it appears that this is not the case.

As was anticipated in Geodetic Report Vol. III, page 81, the compensated geoid in Kashmīr lies in considerably closer agreement with the Survey of India No. II spheroid than it does with the International spheroid. That this should be the case inside India was to be expected, since the Survey of India No. II spheroid was obtained by solving for the spheroid which would best fit the compensated geoid in India, but it was not necessarily to be expected that future extensions of the geoid would point the same way. The superiority of the fit between the compensated geoid and the Survey of India No. II spheroid is especially noticeable when the relationship between the gravity anomalies and the geoidal undulations are considered. It is not to be expected that $g - \gamma_c$ should be directly proportional to the height of the compensated geoid above the spheroid, nor even that all stations of positive gravity anomaly should lie on elevated parts of the geoid, but where several gravity stations indicate a definite area of excess or defect, the compensated geoid may be expected to show some corresponding undulation. If the International spheroid is accepted as a standard, the compensated geoid shows very little correspondence with the variation of gravity. With the exception of a narrow area of defect near Pathānkot and a probable defect north of Skārdu, gravity is continuously in excess (averaging about + 0·020) throughout the line of the section, whereas the compensated geoid falls continuously from north to south reaching a depression of 25 feet in the heavily positive area of Deosai, and then falling even more steeply to the end of the section. When on the other hand the Survey of India No. II spheroid is taken as a standard, gravity and the geoidal section show a reasonably close relationship. The consistently positive gravity anomalies in the south are associated with a high geoid, the Pathānkot deficiency with a small depression, and the excess gravity in Kashmīr is reflected in a corresponding rise. The steep fall of the geoid from Deosai to Skārdu is not in obvious accord with the positive anomalies found there, but it is in accordance with an intense negative area to the north, whose existence is also indicated by De Filippi's station at

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[*] The agreement is not well maintained between 31° and 32°, where the new section gives a further fall of 15 feet compared with 5. This is, however, the extreme edge of the old geoidal chart, and it is an area of heavy anomaly, where good results cannot be expected from widely scattered observations.

Depsang. This Depsang station is 100 miles SE. of the line of the present section, but it has been shown on the gravity anomaly chart at the point where the section cuts the range on which it stands. There is no doubt that, as measured by Hayford's standard, there is a heavy defect of gravity under some parts of the Kara-koram.

If the Survey of India No. II spheroid is accepted as a standard, the good fit of the compensated geoid, compared with that of the natural geoid, shows that in Kashmīr Hayford's hypothesis has been many times more successful than the free air hypothesis in smoothing out geoidal anomalies, although both are equally unsuccessful in removing the widespread rise of the "Hidden Range" in latitudes 26° and 27°. It seems evident that this "Hidden Range" is definitely an anomaly which no generally applicable system can hope to eliminate.

If all the anomalies of density in the earth were confined to a thin superficial layer, it would be possible to locate and measure them by means of gravity observations only. The anomalies having been measured, the geoidal undulations arising from them could be calculated, and if these undulations were subtracted from the observed form of the natural geoid, a perfect spheroid should result. For this to be possible, the superficial layer containing the anomalies must be thin compared with the wave-lengths (crest to crest) of the highest order harmonics necessary for a reasonably accurate representation of the anomalies. This condition is not fulfilled with any accuracy, but the depth (70 miles or less) within which anomalies probably occur is fairly small compared with the size of the major variations of anomaly in India, and a geoidal form calculated from gravity observations should bear broad resemblance to the truth. This process has not been carried out*, but the relation between gravity and the geoid in Kashmīr and the Punjab is such as to make it fairly evident that in India the resulting spheroid would resemble the Survey of India No. II spheroid rather than the International spheroid: while in other parts of the world (e.g. the U. S.) the International spheroid might be more likely to result. If different countries give results which are definitely contradictory, it can only be concluded that there do exist widespread anomalies of density at some considerably greater depth than 70 miles. This seems an unlikely hypothesis, and it is not to be accepted without much stronger evidence than is at present available.

8. Deflection observations in Burma.—During 1930-31 No. 15 Party (Triangulation) observed five latitude and azimuth stations near Kengtung (see Chapter VI, para 5), the results of which are conveniently reported in this Chapter, being included in Table 4, pages 72 to 73. The deflections in meridian call for no comment, but those in the prime vertical are liable to serious error on account of doubt in the accuracy of the geodetic azimuth. The nearest Laplace stations are at Chittagong and Akyab, where the accumu-

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* For the reverse process see Geodetic Report Vol. V, page 74, and Charts XIV and XV.

lated azimuth error of the triangulation is + 7″, and these deflections have been computed on the assumption that no further error has accumulated between Akyab and Kengtung. It is, however, probable that the error in geodetic azimuth at Kengtung is more like +10″, in which case the easterly deflections require to be decreased by about 7″, and until the Kengtung Laplace station is observed, these prime vertical deflections must be considered provisional.

TABLE 2.—*Deviation of the vertical in meridian*

Station	Height	Latitude	Longitude	A−G Everest Spheroid	A−G International Spheroid	Hayford anomaly International Spheroid
	feet	° ′	° ′	″	″	″
Poshkar H. S.	8323	34 02	74 30	+13·8	+20·7	+14·3
Gogipatri H. S.	7752	33 52	74 41	+ 3·0	+ 9·9	+ 5·3
Banihāl Pass	9200	30	75 13	−11·6	− 5·1	− 3·3
Nachilani	5000	22	11	−31·3	−24·9	− 5·4
Rāmban	2400	14	15	−33·2	−26·8	− 6·1
Chineni	4000	03	17	−34·8	−28·5	− 7·1
Dramthal	3800	33 01	15	−34·1	−27·9	− 6·3
Udhampur	2500	32 56	08	−35·4	−29·2	− 9·1
Suruin Sar	2100	46	03	−24·9	−18·8	− 7·1
Gurhāgarh H. S.	2031	38	02	−18·4	−12·4	− 1·5
Bhāru-Chak T. S.	1053	27	07	−13·5	− 7·6	0·0
Atalgarh T. S.	943	19	06	− 7·2	− 1·3	+ 4·7
Mailu-Sailu T. S.	856	11	04	− 3·1	+ 2·7	+ 7·7
Shāhpūr T. S.	805	32 02	06	+ 0·5	+ 6·6	+10·3
Siri T. S.	846	31 53	05	+ 1·5	+ 7·2	+10·2
Chowinda T. S.	833	43	03	+ 2·8	+ 8·5	+10·7
Dhīri-kot T. S.	789	35	03	+ 3·0	+ 8·6	+10·7
Kalla T. S.	784	26	02	+ 2·0	+ 7·5	+ 9·4
Sangatpur T. S.	779	18	02	+ 1·0	+ 6·7	+ 8·5
Makhu Purāna	687	31 07	00	− 2·8	+ 2·7	+ 4·2
Dalūwāla T. S.	728	30 59	03	− 1·5	+ 3·9	+ 5·2
Daraoli T. S.	759	49	03	− 0·6	+ 4·7	+ 5·8
Kunandwāla T. S.	745	40	02	+ 0·6	+ 5·8	+ 6·8
Lakarwāla T. S.	736	31	02	+ 1·3	+ 6·5	+ 7·4
Khimūāna T. S.	731	22	01	− 3·1	+ 2·2	+ 2·9
Maihna S.	730	13	00	− 1·7	+ 3·4	+ 4·1
Kaila-Vāndar T. S.	727	30 04	75 00	− 3·0	+ 2·0	+ 2·7
Gar-Wāli T. S.	717	29 56	74 59	− 1·2	+ 3·8	+ 4·4
Tiloka T. S.	710	49	75 02	− 1·8	+ 3·1	+ 3·6
Siwaipur T. S.	697	39	03	− 0·8	+ 4·1	+ 4·5
Sirsa S.	738	32	75 01	− 1·4	+ 3·4	+ 3·8
Bānka S.	710	29 23	74 58	− 1·6	+ 3·2	+ 3·4
Rāmgarh S.	694	29 13	74 59	− 0·8	+ 3·9	+ 4·0
Sīai S.	760	29 01	75 02	− 0·1	+ 4·5	+ 4·2
Rangarri S.	777	28 53	74 59	+ 0·6	+ 5·1	+ 4·5
Mākar Thal S.	830	41	75 02	− 0·6	+ 3·9	+ 3·2
Rām Thal S.	951	30	00	− 0·5	+ 4·0	+ 3·3
Randālia S.	1038	18	02	− 0·6	+ 3·8	+ 2·7
Gūgla-Bhar S.	1112	28 07	01	− 1·2	+ 3·1	+ 2·1
Garinda H. S.	1204	27 56	75 01	− 0·5	+ 3·8	+ 2·9
Bhūmba S.	1261	47	74 56	− 4·5	− 0·2	− 1·2
Maira Dās S.	1317	27 36	74 54	− 1·5	+ 2·7	+ 2·0

(Continued

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

TABLE 2.—*Deviation of the vertical in meridian.*—(*concld.*)

Station	Height	Latitude	Longitude	A−G Everest Spheroid	A−G International Spheroid	Hayford anomaly International Spheroid
	feet	° ′	° ′	″	″	″
Shami Village	1600	27 26	75 01	+ 1·1	+ 5·2	+ 4·4
Pānchwa H. S.	2048	13	74 56	+ 0·8	+ 4·9	+ 4·3
Jusri Village	1300	27 05	46	+ 3·8	+ 7·8	+ 7·2
Kinsirra H. S.	2423	26 54	42	+ 5·0	+ 8·9	+ 8·4
Kharkari Village	1450	45	42	+ 2·3	+ 6·1	+ 5·8
Narwar Village	1500	36	42	+ 1·9	+ 5·7	+ 5·8
Gūdha H. S.	2418	28	46	− 1·5	+ 2·2	+ 2·0
Asapura Village	1500	20	47	− 5·6	− 2·0	− 1·3
Shokli Village	1300	13	50	− 6·8	− 3·2	− 2·5
Bupki H. S.	1878	26 04	74 49	− 5·4	− 1·9	− 1·5
Reban	5447	33 45	75 00	+ 8·0	− 1·2	+ 2·1
Pingalan	5227	33 54	74 56	−16·2	− 9·3	− 1·4
Srīnagar	5198	34 05	74 49	−17·2	−10·2	− 0·3
Zebanwan	8799	04	74 54	−25·6	−18·6	− 1·5
Hayan	6084	14	74 58	−20·8	−13·8	+ 2·2
Sonāmarg	9050	18	75 16	−12*	− 5*	+ 3·3*
Churawan	8151	40	74 54	−16·1	− 8·8	+ 4·1
Minmarg	9351	48	75 05	− 7·5	− 0·2	+ 7·8
Deosai I	13311	34 57	75 15	+ 0·4	+ 7·8	+12·9
Deosai II	12805	35 02	75 24	− 8·0	+15·4	+21·0
Deosai III	12391	34 56	75 26	+18·2	+25·6	+28·3
Wozul Hadur	13921	35 12	75 32	+25·7	+33·2	+13*
Skārdu	7326	35 18	75 39	+28·3	+35·8	+29*

* Approximate.

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

SECTION II

The traverse across the Great Indian Desert

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

9. Programme.—As a part of the gravity and gradiometer programme of No. 14 Party the desert was crossed roughly about Lat. 28° N. from Reti NE. of Sukkur to Kolait SW. of Bīkaner, a total distance of 212 miles. The opportunity was taken to make observations for deflection in the meridian and prime vertical at nine stations on the line of this traverse; the geodetic positions of these deflection stations were obtained by means of a special theodolite traverse.

10. Personnel and transport.—A small camp consisting of the head clerk and 7 k̇halāsis was left at Reti. The remainder of the party left Reti on 3rd November, 1930, and spent two months on the journey across the desert.

Excluding the camp at Reti, the party was organized for the march as follows:—

I. Traverse section.		
(*a*) Theodolite squad.		
Observer	Major Glennie.	
Recorder	Computer K. M. Laskar.	
Khalāsis		5
(*b*) Hunter Short Base squad.		
Computer Mukhtar	Ahmed (in charge)	
Khalāsis		6
II. Gradiometer section.		
Observer	Mr. L. D. Joshi, U. S. S.	
Khalāsis		12
III. Headquarters.		
Khalāsis		4
Private servants		2
Camel men		27
Load camels		71
Riding camels		2

11. Equipment.—Besides tents, pendulum, astrolabe, gradiometer and traverse equipment, eighteen camel tanks of 13 gallon capacity and rations were carried.

Rations for the khalāsis comprised :—

Rice	30 maunds
Ata	30 ,,
Dāl	8 ,,
Potatoes	4 ,,
Onions	5 ,,
Salt	2 ,,

The dāl remained over at the end of the trip as the well-water was found to be unsuitable for cooking it. Dāl should not be taken into the desert, unless it is anticipated that rain water will be available. The camel men carried their own supplies and had to replenish en route by sending to Kishangarh and Vijnot. The stock of food-stuff available for sale at these places is meagre and very expensive. Poultry, goats and sheep could be obtained from the nomads in the desert, but no other supplies.

12. Nature of the country.—The first nine miles E. by S. of Reti was through flat irrigated country. Longwāli H. S. (Lat. 28° 02′, Long. 70° 00′), the site of the first camp, was on the fringe of the real desert.

From here on, the route kept a mile or two north of Lat. 28° as far as Long. 70° 38′ and then gradually sagged to 8 miles south of Lat. 28° finally swinging NE. at Long. 72° 13′ so as to close on Uperthal H. S. The route was straight across country as no tracks led to the east.

The desert region falls into three main types :—

(*i*) From Longwāli to Kandera Fort (Lat. 28° 01′, Long. 70° 12′) are high sand dunes in parallel lines 1½ miles apart, with a W. by S. strike, and the steep face of the dune on the north side (as was the case all through the desert). In between the dunes were flat areas of "pat". It would be possible for ordinary motor cars to reach Kandera Fort without much difficulty but they could not go eastwards beyond this.

(*ii*) The next section extends to about 45 miles east of Kandera. Here the maximum dune development is found and water is exceedingly scarce. The dunes start on the west with a W. by S. strike and gradually veer round through west to W. by N.

Proceeding east from Kandera transverse ridges begin to form on the dunes, becoming more and more prominent. As the main ridges move northwards these transverse ridges tail out behind in long spurs and are over-ridden by the next dune, so that the valleys between the main dunes are crossed by sand ridges and the hard "pat" areas grow smaller, vanishing altogether at the east edge.

The sand is coarse and firm, thorns are absent and the dunes are thickly dotted with bushes four or five feet high, so that there is no glare and marching is pleasant. Camel food is plentiful but there are some poisonous plants unknown to the Sind camels. Three of these died in consequence.

Measurements in the centre of this area showed a general northerly movement of the dunes amounting to about 1½ furlongs since the survey in 1873, that is an annual movement of about 15 feet.

The highest dune in this area was about 200 feet high above the "pat"; the steep north face of the dune was about 150 feet high.

(*iii*) On the east edge of the main dune area, the dunes crowd in until they are ¼ mile or less apart. This appears to be the result of stagnation, and the next type of desert begins abruptly. This is a low lying area of soft sand, thickly covered with hummocks of spiny grass, very wearisome to march through. There are low sand ridges about 30 feet above the general level which appear to be the last relics of the transverse ridges of the main dune area.

After some 50 miles of this, cultivated areas appear, gradually increasing in size and frequency. Uperthal H. S. (Lat. 28° 00′, Long. 72° 15′) and Mankasar H. S. (Lat. 28° 00′, Long. 72° 29′) mark a small belt of high, widely separated sand dunes. Eight miles beyond Mankasar a hard *kankar* plain is reached and the sandy desert has been left behind.

13. Water.—The rains had failed in the summer and all the "tobas" were dry. The 18 camel tanks taken with the party were really insufficient and water supply was decidedly precarious at times. Water was obtained from wells and usually had to be drawn in the early hours of the morning since in the day time the water was exhausted in supplying water for cattle. The wells were usually eight or more miles from the camp, and at one place water had to be fetched from a distance of nineteen miles.

Water was of two kinds——brackish (*khāri*) and bad (*karwa*). The former contained common salt and was much relished in comparsion with *karwa* water which perhaps contained magnesium salts and from one place was almost poisonous, causing boils, tooth-ache, ear-ache, and stomach-ache.

On the east edge of the desert the villagers store rain-water in covered pits lined with *kankar* lime mortar. This stored water is very sweet and clean. East of Long. 71° 30′ wells were never more than two or three miles from the route and usually one containing brackish water could be selected.

Stored rain-water was obtainable at times.

14. Inhabitants.—In the 1st and 2nd sections of the route there are only nomad shelters of the most temporary character. There are plenty of cattle, large flocks of sheep and nomad encampments with poultry in the sand dune area. Except for the cattle they seem to be almost independent of water in the cold weather. The cattle go daily unattended eight or more miles to the wells where men are on duty to water them. The inhabitants were very friendly, but the fact that a local guide was engaged at Kandera almost certainly prevented trouble at the wells.

Wolves are common in the central part of the desert, and gazelle and great bustard are common everywhere. There were some partridge, but sand grouse were noticeably absent.

15. Temperature.—The maximum day temperature varied between 70°F. and 80°F.; at night it usually dropped to about 35°F. and on many occasions there was hard frost. There was very little wind, and visibility was excellent throughout, with no dust haze and remarkably little radiation.

16. The traverse.—Starting at Longwāli H. S. with a ray to Vijnot T.S., a traverse was run across the desert closing at Uperthal H. S.

A small Wild theodolite was employed and a Hunter Short Base served as a subtense (4 chains long). A short account of the Hunter Short Base (see Plate VIII of this volume for the new model) appears in Geodetic Report Vol. IV and Departmental Paper No. 10, 1931. Subtense angles were taken on 12 zeros at 15° intervals, 6 zeros on each face. Traverse angles were taken on 6 zeros, 3 on each face. Vertical angles were taken in the forward direction only.

Results of the traverse are summarized below.

Traverse Results

Length of traverse	147·55	miles
Average subtense distance ...	1·76	,,
Average subtense angle ...	1°48′	
Max. subtense distance ...	3·4	miles
Number of base stations ...	42	
Total number of stations ...	85	
Closing error in latitude ...	1″·47	
Closing error in longitude ...	1″·42	
Accuracy	1 in 6125	
Average probable error of single subtense observation ...	±2″·76	

Traverse results—(contd.)

Average probable error of mean subtense observation ...	±0″·79
Traverse height of Uperthal H.S.	623 ± 6 ft. above M.S.L
G.T. height of Uperthal H.S. ...	622 ft. above M.S.L.

The closing errors were distributed uniformly along the line of traverse. The uncertainty of 6 feet in the height is due to an unfortunate error in reading (or recording) the vertical angles at one station. The reading on the two faces are incompatible, one showing elevation and the other depression. It is fair to assume that one of these readings is correct, but it is not now possible to decide which is the correct one.

The traverse heights along the route show that the ground level of the "pat" rises at a fairly steady rate of about 1½ feet per mile between Longwāli and Uperthal.

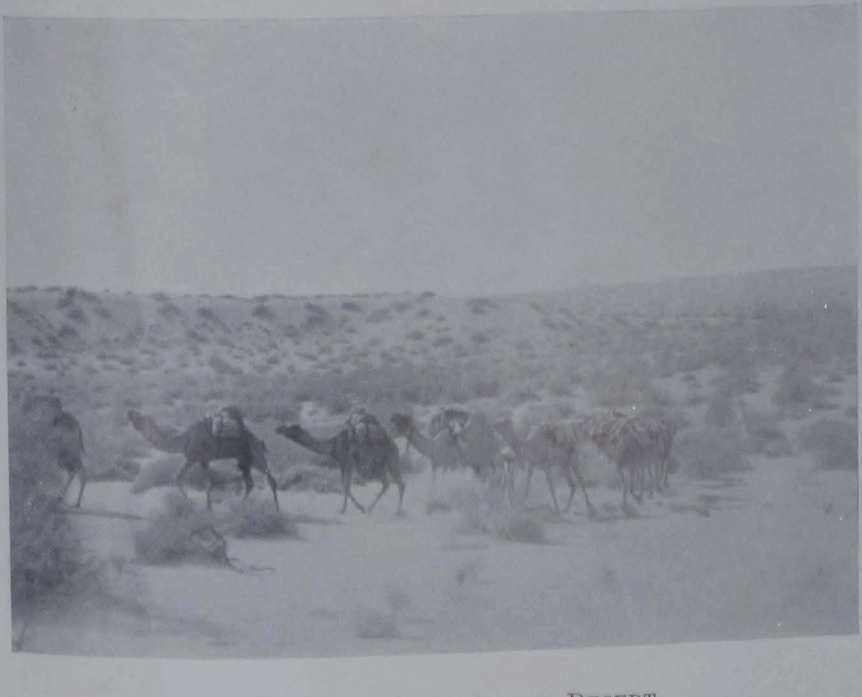
"Pat" level at Longwāli ...	243 ft. above M.S.L.
"Pat" level at Uperthal ...	460 ft. above M.S.L.

The subtense angles on 12 zeros have been examined to see if there is any indication of systematic errors in the dividing of the horizontal circle of the Small Wild Theodolite (No. 1702). No systematic error can be detected.

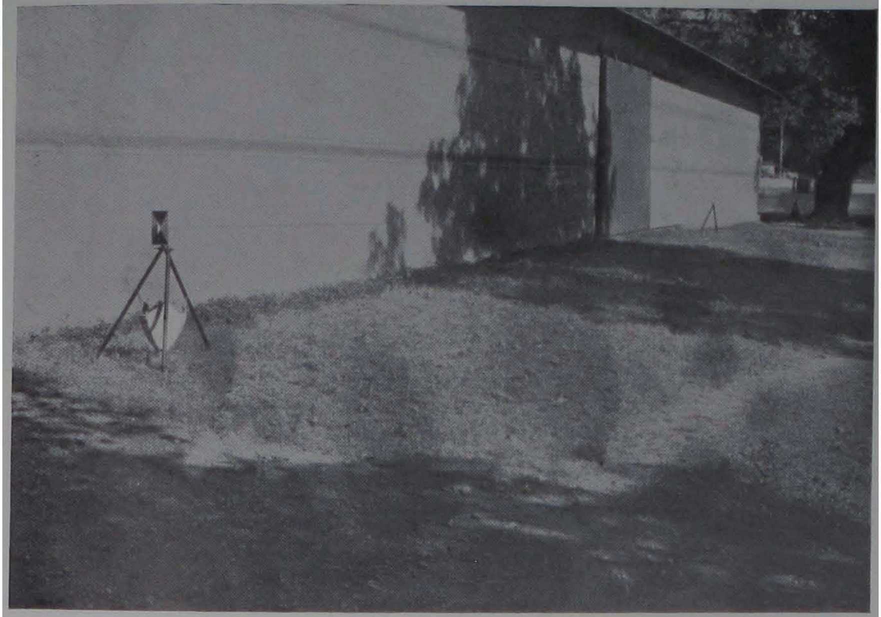
17. Method of traverse.—The Hunter Short Base was set up at alternate stations as nearly as possible at right angles to the traverse line. (At times owing to terrain difficulties the base angle was only slightly over 42°). A special target was plumbed over each end, (see Plate VII), and similar targets were set up to mark the theodolite stations from which subtense angles were taken in both forward and backward directions to each base. Traverse angles were taken at both theodolite and base stations, and in addition at base stations the base angle was measured at one end of the base.

The special targets were excellent up to 3½ miles so long as the sun was slightly oblique to them, either in front or behind, but if it was in the same plane (i. e. at about midday) the targets tended to vanish completely for about ¾ hour. Only four targets were carried in the field, which were insufficient and led to long delays while targets were being carried forward. A fifth target was extemporised out of a camera tripod but was not very satisfactory. The traverse party should have had six or seven targets and three or four more khalāsis. On account of this shortage, three legs of the traverse was a good day's out-turn and was never exceeded, hence in order to traverse 7 or 8 miles a day the subtense distances had to be made very much longer than had originally been intended and

Special Target in use with Hunter Short Base.



Scene in the Great Indian Desert.



HUNTER SHORT BASE (NEW MODEL). SHOWING POST A AND ONE INTERMEDIATE SUPPORT.

HUNTER SHORT BASE (NEW MODEL). SHOWING POST B.

the accuracy of the traverse suffered in consequence. With shorter subtense distances and a stricter alignment of the base it seems certain that really precise results could be obtained, and this method is probably the best way of traversing a desert of this nature.

The responsible task of selecting sites for all stations, setting up the base and centring the targets was carried out by B. Mukhtar Ahmed.

The base line was standardized at Dehra Dūn at the beginning and end of the field season and was found to have increased 0·006 feet during the field season. The mean value of the length of the base at the beginning and end of the field season was used throughout the traverse.

18. Deflections.—Deflections were obtained by astronomical observations with the large prismatic astrolabe, Claude and Driencourt pattern (Geodetic model) by S. O. M., vide Plate IV, Geodetic Report, Vol. III.

Auxiliary apparatus employed were the Marconi R. P. 11 Wireless receiver and one of the two break-circuit chronometers by Thomas Mercer used for pendulum observations, a drum chronograph by Thomas Mercer, and the personal equation apparatus designed by Capt. Bomford, R.E., which is described in Geodetic Report Vol. III, Chap. VIII. A very short programme of observations was employed of three or four hours only, comprising as a rule six groups of stars, one in each quadrant. The wireless time signal transmitted by Rugby at eighteen hours G.M.T. was used, except at Aqilwāla when the Nauen signal at noon G.M.T. was employed.

19. Results.—The deflections obtained are shown in Table 4; the personal equation and probable errors are shown in Table 3.

TABLE 3—*Astronomical Stations*

No.	Place	Personal equation	Number of groups	Probable error of Astronomical Determination.	
				Meridian	Prime Vertical
		s		"	"
601	Longwāli ...	−0·04	6	±0·54	±0·35
602	Kandera ...	+0·02	6	±0·19	±0·16
603	Dinga ...	−0·01	6	±0·08	±0·32
604	Gorhelawāla ...	+0·01	6	±0·42	±0·60
605	Barsiwāla ...	−0·01	6	±0·56	±0·24
606	Matwāri ...	**	5	±0·30	±0·24
607	Aqilwāla ...	+0·04	6	±0·29	±0·24
608	Charanwāla ...	−0·02	6	±0·34	±0·29
609	Uperthal ...	+0·04	4	±0·43	±0·24
	Mean	0·00	...	±0·35	±0·30

* At Matwāri the personal equation apparatus was out of action owing to a temporary failure in the electrical circuit.

It is evident that the deflections may be considered correct to within two seconds of arc. This accuracy is sufficient, since the geoid is better obtained from data of moderate accuracy at closely spaced stations than from precise data sparsely distributed.

20. Deductions.—Sections and contours of the geoid are shown on Charts IX and X. Gravity anomalies are also shown. The uniform southerly deflections may be due to (*i*) excess mass to the south (*ii*) deficient mass to the north, (*iii*) a combination of the two. The latter is the more probable.

The marked uniformity of the southerly deflections indicates a great uniformity of the disturbing feature with a probability that it is fairly distant and deep-seated.

It is likely that the southerly deflections are almost entirely due to the Hidden Range, and that associated with the low gravity anomalies at Dera Ghāzi Khān there is a bay in the range pushing its crest south of the assumed crest line on Chart VI of Geodetic Report Vol VI. If the crest of the Hidden Range remains in the position assumed in Geodetic Report Vol. VI the southerly deflection due to it is rather less than 2 seconds of arc. A slight shift of the crest south is insufficient fully to account for the southerly deflections, and it is therefore likely that we have here in addition a rise in the Hidden Range associated with a deepening of the trough near Dera Ghāzi Khān. Rocky outcrops near Jaisalmer are cited in confirmation of this assumption.

The high gravity value at Matwāri without a corresponding rise in the geoid probably indicates a narrow ridge of rock of normal density rising fairly close to the surface of the alluvium. This would be a promising place for a boring to prove the bed-rock.

THE GEOID

Chart IX

Horizontal Scale 1 Inch = 32 Miles

Deflection Scale 1 Inch = 20 Seconds

Fig. I

Section on Lat 28° N.

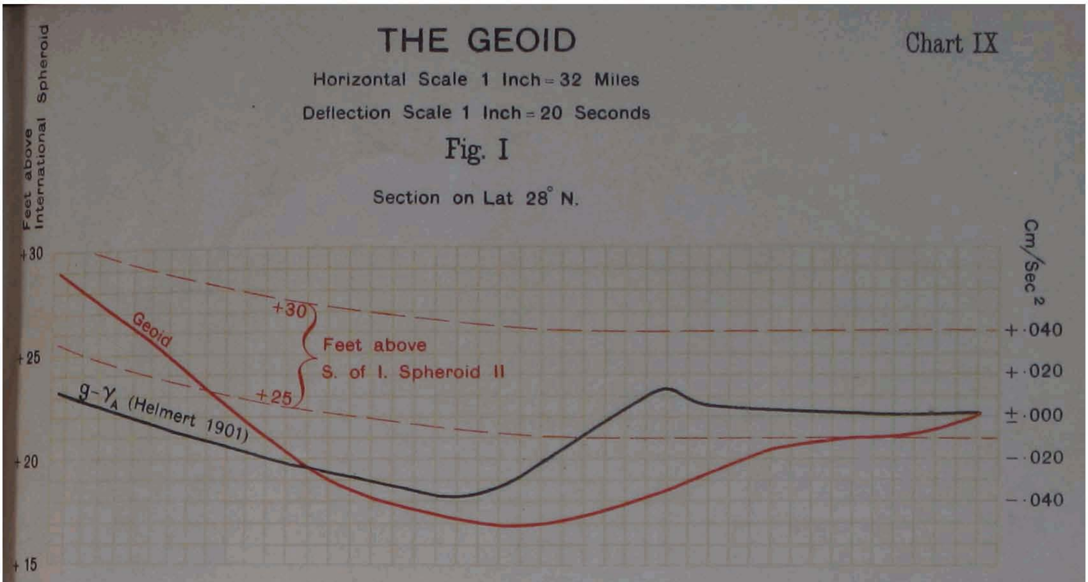


Fig. II

Geoid Contours (International Spheroid)

Values of $g-\gamma_A$ (Helmert 1901)

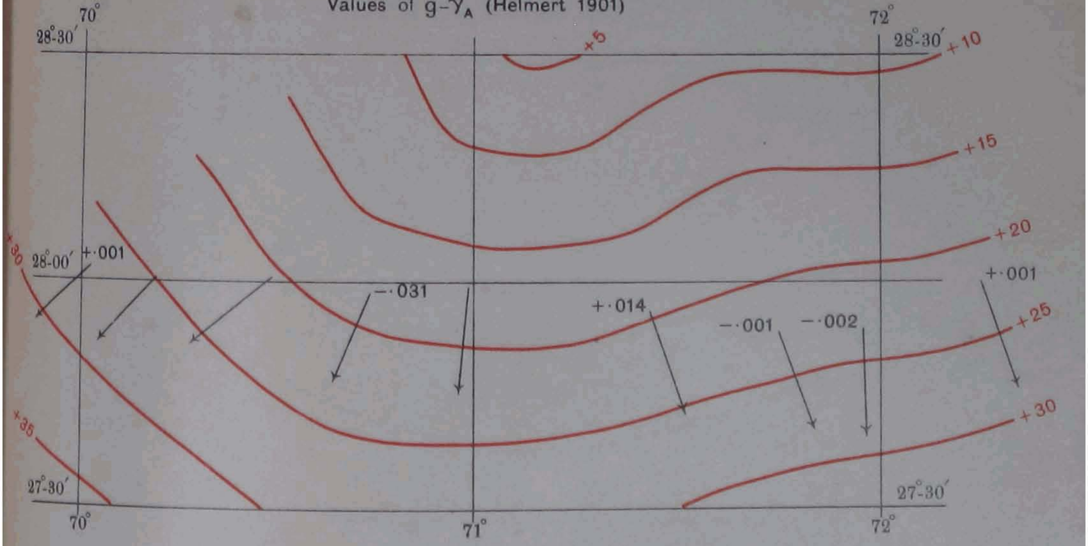
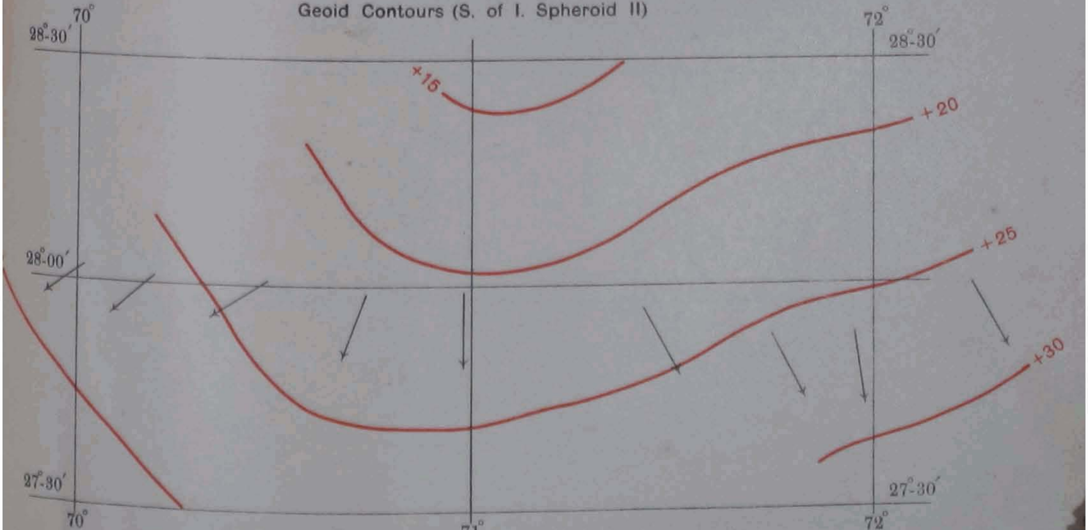


Fig. III

Geoid Contours (S. of I. Spheroid II)



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H.S.I.O. Dehra Dun.

THE COMPENSATED GEOID

Chart X

Horizontal Scale 1 Inch = 32 Miles

Deflection Scale 1 Inch = 20 Seconds

Fig. I

Section on Lat 28° N.

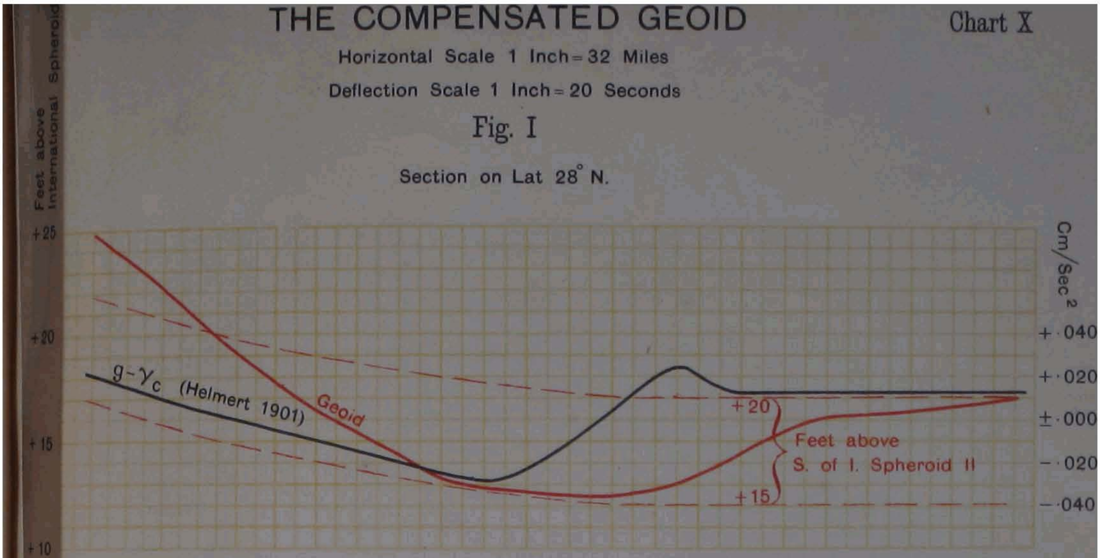


Fig. II

Geoid Contours (International Spheroid)

Values of $g-\gamma_c$ (Helmert 1901)

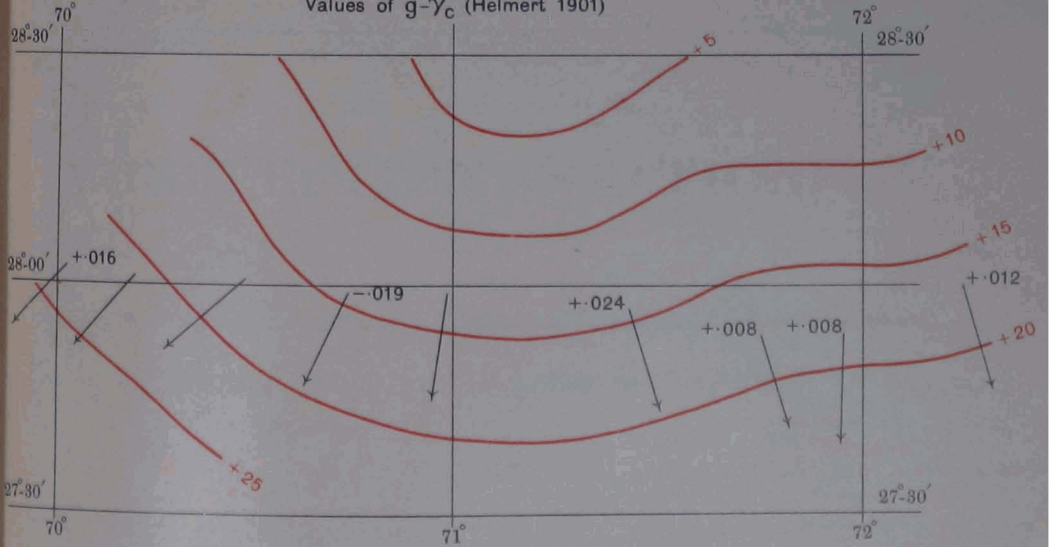
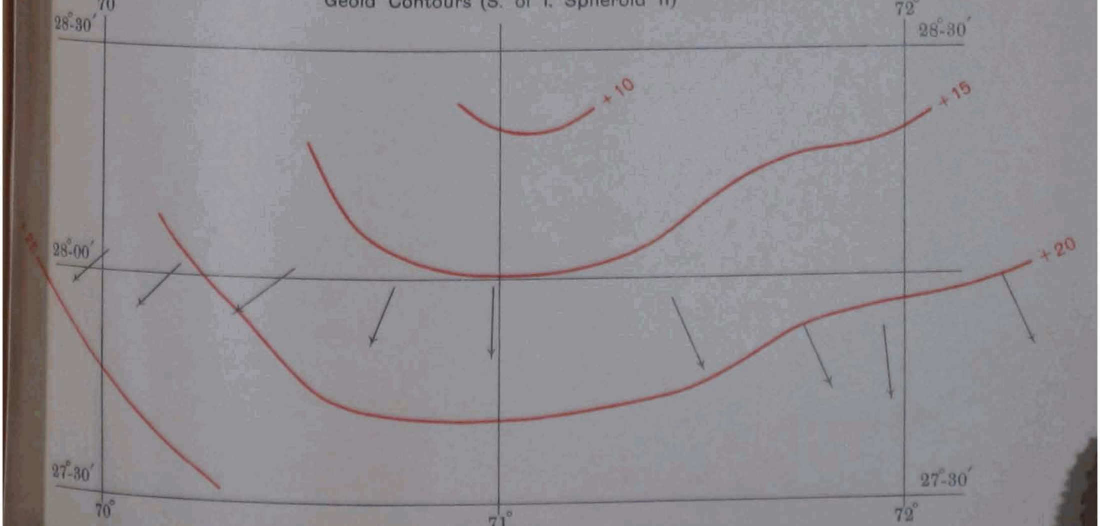


Fig. III

Geoid Contours (S. of I. Spheroid II)



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H.S.I.O.Dehra Dūn.

DEFLECTION STATIONS

First 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.
				″	″	″	″	″	″
566	39 L	Longwāli ...	243	+ 5·6	+ 6·6	− 0·5	+ 0·2	−34†	− 8†
567	L	Dinga ...	395	+ 7·0	+ 8·4	− 0·2	− 0·0	−32†	−10†
568	L	Kandera ...	305	+ 6·8	+ 6·5	− 0·3	0·0	−33†	− 9†
569	40 I	Barsiwāla ...	342	+ 10·6	+ 1·0	+ 0·1	− 0·1	−31†	−12†
570	I	Gorhelawāla ...	319	+ 9·3	+ 4·0	0·0	− 0·1	−31†	−11†
571	40 M	Matwāri ...	356	+ 10·3	− 3·6	+ 0·1	− 0·2	−31†	−13†
572	M	Aqilwāla ...	414	+ 9·3	− 3·2	+ 0·2	− 0·3	−30†	−15†
573	M	Charanwāla ...	443	+ 10·8	− 0·4	+ 0·2	− 0·3	−29†	−15†
574	43 O	Banihāl Pass ...	9200	− 5·1		− 1·8		−38*	
575	O	Nachilani ...	5000	−24·9		−19·5		−57*	
576	O	Rāmban ...	2400	−26·8		−20·7		−62*	
577	O	Chineni ...	4000	−28·5		−21·4		−60*	
578	O	Dramthal ...	3800	−27·9		−21·6		−62*	
579	P	Udhampur ...	2500	−29·2		−20·1		−60*	
580	P	Suruin Sar ...	2100	−18·8		−11·7		−49*	
581	P	Gurhāgarh H.S.	2031	−12·4		−10·9		−49*	
582	P	Bhūru-Chak T.S.	1053	− 7·6		− 7·6		−42*	
583	P	Atalgarh T.S.	943	− 1·3		− 6·0		−39*	
584	P	Mailu-Sailu T.S.	856	+ 2·7		− 5·0		−39*	
585	44 J	Maihna S.	730	+ 3·4		− 0·7		−16*	
586	K	Gar-wāli T.S.	717	+ 3·8		− 0·6		−15*	
587	K	Bānka S.	710	+ 3·2		− 0·2		−10*	
588	K	Rāmgarh S.	694	+ 3·9		− 0·1		−10*	
589	L	Rangarri T.S.	777	+ 5·1		+ 0·6		− 7*	
590	M	Siri T.S	846	+ 7·2		− 3·0		−33*	

* Topography to 400 miles.
† Topography to 417 miles.

DEFLECTIONS 1930–31

EVEREST'S SPHEROID						Serial No.
Latitude	Longitude	Azimuth	Name of station observed for Azimuth	Deflections		
				Meridian	P. V.	
° ′ ″	° ′ ″	° ′ ″		″	″	
A 28 02 06·9 G 28 02 05·5	*A* 70 00 37·1 *G* 70 00 27·8			+ 1·4	+11·0	566
A 28 01 22·3 G 28 01 19·5	*A* 70 29 52·0 *G* 70 29 41·0			+ 2·8	+12·5	567
A 28 01 05·5 G 28 01 02·9	*A* 70 12 00·3 *G* 70 11 51·2			+ 2·6	+10·8	568
A 27 59 37·3 G 27 59 30·9	*A* 70 58 59·6 *G* 70 58 57·2			+ 6·4	+ 4·9	569
A 27 59 28·5 G 27 59 23·4	*A* 70 44 31·6 *G* 70 44 25·7			+ 5·1	+ 8·0	570
A 27 57 18·9 G 27 57 12·8	*A* 71 25 20·6 *G* 71 25 23·7			+ 6·1	+ 0·1	571
A 27 53 45·1 G 27 53 40·0	*A* 71 44 39·5 *G* 71 44 42·3			+ 5·1	+ 0·3	572
A 27 53 44·1 G 27 53 37·5	*A* 71 57 16·7 *G* 71 57 16·7			+ 6·6	+ 2·8	573
A 33 30 16·6 G 33 30 28·2	*G* 75 12 48·2			−11·6		574
A 33 21 21·9 G 33 21 53·2	*G* 75 10 36·8			−31·3		575
A 33 13 39·5 G 33 14 12·7	*G* 75 14 37·1			−33·2		576
A 33 01 57·4 G 33 02 32·2	*G* 75 17 12·2			−34·8		577
A 33 00 47·7 G 33 01 21·8	*G* 75 14 38·0			−34·1		578
A 32 55 16·4 G 32 55 51·8	*G* 75 08 09·2			−35·4		579
A 32 45 38·4 G 32 46 03·3	*G* 75 02 31·7			−24·9		580
A 32 37 41·5 G 32 37 59·9	*G* 75 02 05·3			−18·4		581
A 32 26 42·4 G 32 26 55·9	*G* 75 06 45·1			−13·5		582
A 32 18 37·7 G 32 18 44·8	*G* 75 06 26·8			− 7·2		583
A 32 10 36·9 G 32 10 40·1	*G* 75 04 24·3			− 3·1		584
A 30 13 10·0 G 30 13 11·6	*G* 74 59 42·8			− 1·7		585
A 29 55 52·2 G 29 55 53·4	*G* 74 59 14·8			− 1·2		586
A 29 22 41·9 G 29 22 43·5	*G* 74 58 07·0			− 1·6		587
A 29 13 03·7 G 29 13 04·5	*G* 74 59 12·1			− 0·8		588
A 28 53 27·1 G 28 53 26·5	*G* 74 59 04·3			+ 0·6		589
A 31 52 37·7 G 31 52 36·1	*G* 75 04 42·4			+ 1·5		590

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

TABLE 4

Serial No.	Sheet No.	Observed at	Height in feet	International Spheroid Deflections		Calculated Deflections, Hayford System		Calcuted Deflections. Uncompensated Topography to 2564 miles	
				Meridian	P.V.	Meridian	P.V.	Meridian	P.V.
				″	″	″	″	″	″
591	44 M	Chowinda T.S.	833	+ 8·5		− 2·2		−29*	
592	M	Dhiri-kot T.S.	789	+ 8·6		− 2·1		−28*	
593	M	Kalla T.S.	784	+ 7·5		− 1·9		−27*	
594	M	Makhu Purāna	687	+ 2·5		− 1·5		−24*	
595	N	Dalūwāla T.S.	728	+ 3·9		− 1·3		−23*	
596	N	Daraoli T.S.	759	+ 4·7		− 1·1		−21*	
597	N	Kunandwāla T.S.	745	+ 5·8		− 1·0		−20*	
598	N	Lakarwāla T.S.	736	+ 6·5		− 0·9		−19*	
599	N	Kaila-Vāndar T.S.	727	+ 2·0		−0·7		−15*	
600	O	Tiloka T.S.	710	+ 3·1		−0·5		−14*	
601	O	Sirsa S.	738	+ 3·4		−0·4		−12*	
602	O	Sīai S.	760	+ 4·5		+0·3		− 8*	
603	P	Mākar Thal S.	830	+ 3·9		+0·7		− 6*	
604	P	Randālia S.	1038	+ 3·8		+1·1		− 4*	
605	P	Gūgla-Bhar S.	1112	+ 3·1		+1·0		− 3*	
606	45 A	Uperthal	460	+10·2	−3·7	+0·3	−0·5	−29†	−16†
607	I	Bhūmba S.	1261	− 0·2		+1·0		− 2*	
608	I	Maira Dās S.	1317	+ 2·7		+0·7		− 2*	
609	I	Pānchwa H.S.	2048	+ 4·9		+0·6		− 1*	
610	I	Jusri Village	1300	+ 7·8		+0·6		0*	
611	J	Kinsirra H S.	2423	+ 8·9		+0·5		0*	
612	J	Kharkari Village	1450	+ 6·1		+0·3		+ 1*	
613	J	Narwar Village	1500	+ 5·7		−0·1		+ 1*	
614	J	Gūdha H.S.	2418	+ 2·2		+0·2		+ 1*	
615	J	Asapura Village	1500	− 2·0		−0·7		0*	

*Topography to 417 miles.
†Topography to 400 miles.

DEFLECTIONS 1930-31.—(*Contd.*)

EVEREST'S SPHEROID						Serial No.
Latitude	Longitude	Azimuth	Name of Station observed for Azimuth	Deflections		
				Meridian	P.V.	
° ′ ″	° ′ ″	° ′ ″		″	″	
A 31 43 16·5 G 31 43 13·7	*G* 75 03 24·3			+ 2·8		591
A 31 34 56·6 G 31 34 53·5	*G* 75 03 01·8			+ 3·0		592
A 31 26 10·7 G 31 26 08·7	*G* 75 01 41·0			+ 2·0		593
A 31 06 46·2 G 31 06 49	*G* 75 00 11			− 3		594
A 30 59 05·4 G 30 59 06·9	*G* 75 03 23·5			− 1·5		595
A 30 48 35·6 G 30 48 36·2	*G* 75 02 45·9			− 0·6		596
A 30 39 38·5 G 30 39 37·9	*G* 75 01 53·8			+ 0·6		597
A 30 30 35·2 G 30 30 33·9	*G* 75 02 15·0			+ 1·3		598
A 30 03 45·2 G 30 03 48·3	*G* 75 00 09·6			− 3·0		599
A 29 49 01·2 G 29 49 03·0	*G* 75 01 30·4			− 1·8		600
A 29 31 34·0 G 29 31 35·4	*G* 75 01 14·8			− 1·4		601
A 29 01 02·7 G 29 01 02·8	*G* 75 01 30·0			− 0·1		602
A 28 41 16·6 G 28 41 17·2	*G* 75 01 59·9			− 0·6		603
A 28 18 04·9 G 28 18 05·5	*G* 75 01 40·0			− 0·6		604
A 28 07 16·3 G 28 07 17·5	*G* 75 01 23·4			− 1·2		605
A 28 00 03·8 G 27 59 57·9	*A* 72 14 38·3 *G* 72 14 42·2			+ 5·9	− 0·7	606
A 27 46 37·3 G 27 46 41·8	*G* 74 56 25·0			− 4·5		607
A 27 35 58·0 G 27 35 59·5	*G* 74 53 43·8			− 1·5		608
A 27 13 30·4 G 27 13 29·6	*G* 74 55 51·7			+ 0·8		609
A 27 04 36·1 G 27 04 32·3	*G* 74 45 30·0			+ 3·8		610
A 26 54 30·4 G 26 54 25·4	*G* 74 42 00·3			+ 5·0		611
A 26 44 39·7 G 26 44 37·4	*G* 74 42 05·2			+ 2·3		612
A 26 36 11·2 G 26 36 09·3	*G* 74 41 32·4			+ 1·9		613
A 26 28 08·5 G 26 28 09·9	*G* 74 26 06·1			− 1·5		614
A 26 19 49·7 G 26 19 55·3	*G* 74 47 05·7			− 5·6		615

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

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.
				″	″	″	″	″	″
616	45 J	Shokli Village	1300	− 3·2		−0·7		0*	
617	J	Bupki H.S.	1878	− 1·9		−0·4		0*	
618	M	Shami Village	1600	+ 5·2		+0·8		− 1*	
619	93 O	Kengtung North Base	2552	+ 1	−19	−3·6	+ 2·8		
620	O	Loi Hpalan H.S.	7613	+ 8	− 1	−0·3	+7·6		
621	O	Kengtung Centre Base	2541	+ 3	−19	−1·7	+1·3		
622	O	Loi Makho H.S.	6216	+11	−22	+3·0	−7·5		
623	O	Kengtung South Base	2581	+ 8	− 9	+1·0	+1·9		

---

* Topography to 417 miles.

† Topography to 400 miles.

DEFLECTIONS 1930-31.—(*Concld.*)

EVEREST'S SPHEROID						
Latitude	Longitude	Azimuth	Name of Station observed for Azimuth	Deflections		Serial No.
				Meridian	P. V.	
° ′ ″	° ′ ″	° ′ ″		″	″	
A 26 12 49·0 G 26 12 55·8	*G* 74 50 27·4			− 6·8		616
A 26 03 50·1 G 26 03 55·4	*G* 74 49 14·3			− 5·4		617
A 27 26 07·3 G 27 26 06·2				+ 1·1		618
A 21 24 37 G 21 24 36	*G* 99 36 58	A 86 12 42 G 86 13 02	Loi Hpalan	+ 1	−33 *	619
A 21 24 15 G 21 24 07	*G* 99 29 13	A 200 25 50 G 200 26 03	Loi Mi	+ 8	−15 *	620
A 21 21 33 G 21 21 30	*G* 99 36 46	A 110 19 54 G 110 20 14	Loi Hpalan	+ 3	−33 *	621
A 21 18 34 G 21 18 23	*G* 99 46 50	A 145 32 02 G 145 32 23	Loi Mi	+ 11	−36 *	622
A 21 18 24 G 21 18 16	*G* 99 36 33	A 130 27 21 G 130 27 37	Loi Hpalan	+ 8	−23 *	623

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

*These Prime Vertical deflections are provisional only. They probably require a correction of about + 7″. See Chap. IV. para 8.

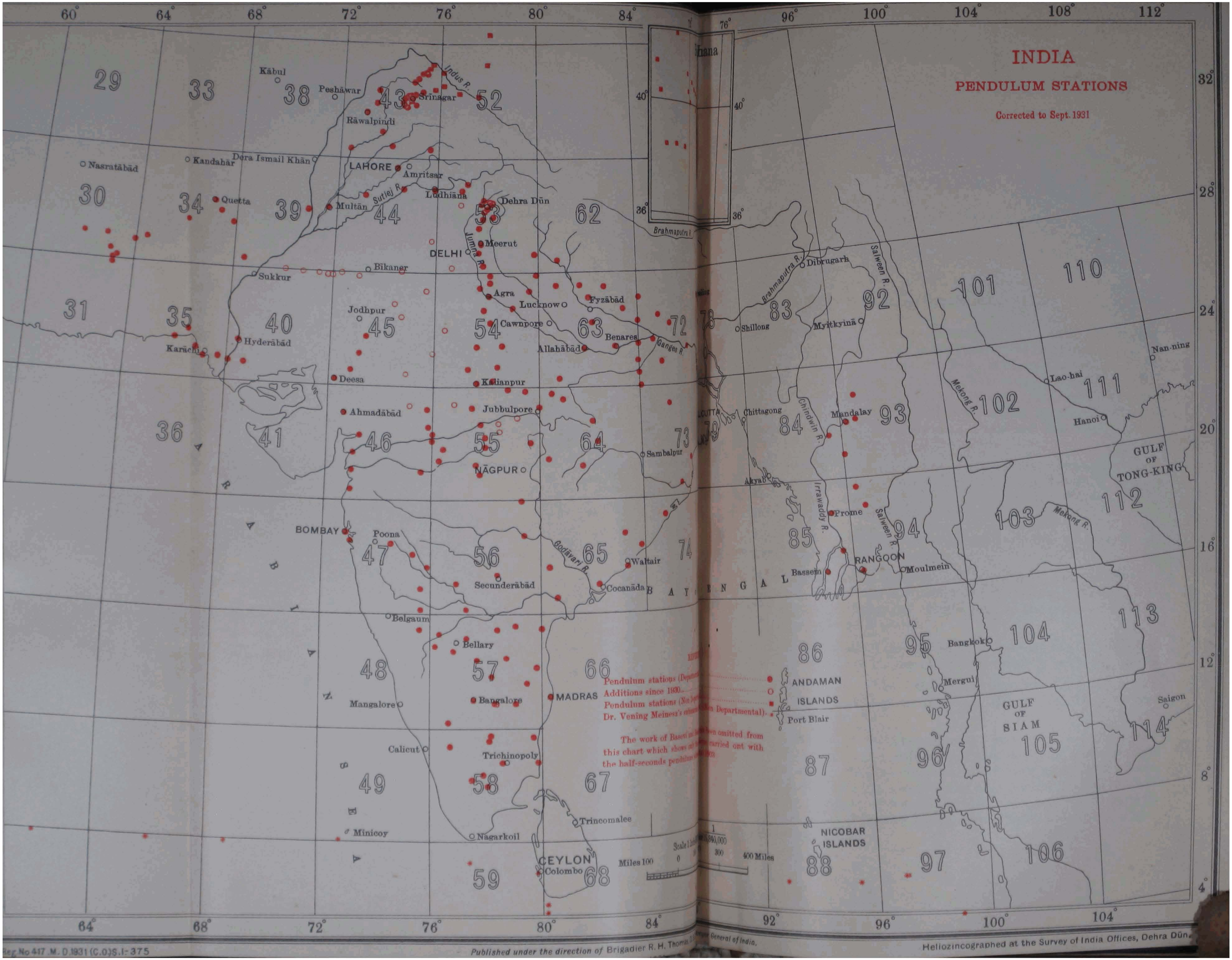
TABLE 5.—*Isostatic and Topographical Deflections*

The following stations appear in Table 1 of the Supplement to Geodetic Report Vol. VI, without entries relative to deflections calculated on the Hayford and uncompensated topography systems.

The reductions have now been carried out.

Serial No.	Sheet No.	Observed at	Calculated Deflections Hayford System		Calculated Deflections Uncompensated Topography to 417 miles	
			Meridian	P. V.	Meridian	P. V
			″		″	
76	43 J	Poshkar ...	+ 6·4		– 25	
77	J	Zebanwan ..	– 17·1		– 50	
89	K	Gogipatri ...	+ 4·6		– 28	
90	K	Reban ...	– 3·3		– 38	
97	43 P	Shāhpūr ...	– 3·7		– 35	
105	44 M	Sangatpen ...	– 1·8		– 26	
129	45 M	Garinda ..	+ 0·9		– 2	
525	52 E	Depsang Transit S.	– 2 6	– 2·2	+ 7*	– 13*

* Topography to 400 miles.



INDIA
PENDULUM STATIONS
Corrected to Sept. 1931

Reg. No 417 .M. D.1931 (C.O.)S.I.-375

Published under the direction of Brigadier R. H. Thoma General of India.

Heliozincographed at the Survey of India Offices, Dehra Dūn.

CHAPTER V

GRAVITY

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

(i) FIELD SEASON 1930-31

1. Programme.—Observations during the field season were planned to fill in a large blank in the north-west of Peninsular India. Work commenced with a line of seven stations spaced across the Great Indian Desert at about lat. 28° N. from Longwāli 60 miles NE. of Sukkur to Kolait 25 miles SW. of Bikaner. Gravity work on this line was carried on *pari passu* with a theodolite traverse and astrolabe and gravimetrical observations. These are described in other parts of this report. (See pp. 61 to 67).

After leaving Kolait use was made of the numerous railway systems to cover rapidly the area centred about Long. 76° E. from Ambāla in the north to Ratlām in the south. Twelve gravity stations in all were established in this area.

Observations were also made at Pachmarhi and at Piparia and Narsinghpur in the Narbada valley.

2. Strength of the party.—The gravity party consisted of one officer, one clerk, two computers and thirty-four khalāsis. This establishment was bigger than usual owing to the extra work to be done during the desert traverse.

Health was excellent throughout the field season until the return to Dehra Dūn when two khalāsis became seriously ill with pneumonia.

3. Apparatus.—The 1926 pattern apparatus and the nickel-steel pendulums described in Geodetic Report Vol. IV were used throughout the season.

Two chronometers by Thos. Mercer (Nos. 12831 & 13560) were employed. Owing to partial failure of the electrical contacts only one chronometer could be used at many stations. Both clocks developed very erratic rates during the field season, but this was not serious, since the method now employed of swinging the pendulums nearly continuously between wireless time signals practically elimi nates clock rate errors.

A more serious matter was the partial failure of the wireless receiver half-way through the desert. The source of the trouble was trivial, and was due to a faulty resistance and a defective joint, but this was not discovered until the return of the party to recess. Reception was exceedingly poor, and frequently the usual method of using the chronometers to cut out the rhythmic signal had to be abandoned in favour of the less accurate method of listening to the signals, and watching the second-hand of the chronometer. When this method is employed there is usually an uncertainty of about 10 seconds in estimating the time of a coincidence. Error did not result, however, except at Ratlām. At this place the gravity result can only be considered correct to 0·01 cm/sec^2.

The wireless receiver, Marconi R. P. 11, has now been in use for five field seasons with thousands of miles of rough travelling each season; so, in spite of its partial failure last field season, its performance can be considered highly satisfactory. The four valves originally installed in the receiver in 1926 are still in use.

4. Details of the observations.—Results are shown in Tables 1 to 4. Table 2 shows that, except at Ratlām, the two pairs of pendulums give results which are satisfactorily in agreement.

At Rewāri there is an uncertainty in the height of the gravity station, which may be in error by nearly ten feet. This is not serious, the resulting error in *g* amounting to only 0·001 cm/sec^2.

(ii) RESULTS OF THE FIELD WORK

5. General description of the area.—The Great Indian desert in the part traversed appears to be a flat plain of alluvium rising from west to east at a steady slope of about 1½ feet per mile. Sand hills, in places 250 feet or more above the general level, rise above this plain, which consists of a sandy loam interspersed in many places with small hard nodules of cemented sand. Patches of hard clay occur in places and here the nomadic inhabitants dig shallow depressions (*tobas*) to catch rain water.

The first six gravity stations from west to east were in the desert area. Kolait is outside the desert area, and there are outcrops of rock in the neighbourhood.

I am indebted to the Director of the Geological Survey of India for the following geological classification of the gravity stations:—

Geological situation of gravity stations.

Station Number	Name	Geology
	I. Indo-Gangetic alluvium	
206	Longwāli	No rock exposures.
207	Gorhelawāla	
208	Matwāri	
209	Aqilwāla	
210	Charanwāla	
211	Uperthal	
213	Ratangarh ...	Igneous rhyolite and tuff 10 miles to SSW. and ESE. respectively.
214	Degāna ...	Granite (with wolfram bearing veins) 2½ miles to SW.
224	Ringas ...	Granite 8 miles to NE.
225	Rewāri ...	Sedimentary quartzites and slates 15 miles and more away.
226	Hissār	No rock exposures.
227	Ambāla	
	II. Aravalli and Delhi Systems	
215	Ajmer ...	On sedimentary quartzites of Delhi system. Granite adjoining to NW.
216	Nimach ...	On Deccan trap and laterite over Arāvalli sediments.
223	Sawai Mādhopur	On sedimentary sandstone (quartzites) of Arāvalli (Gwalior) system. Vindhyans 6 miles to SE.
	III. Miscellaneous	
212	Kolait ..	On Eocene sediments.
217	Ratlām ...	On Deccan trap.
218	Shujāulpur ...	On Deccan trap.
220	Pachmarhi ..	On Gondwāna sediments.
219	Piparia ...	On Narbada alluvium.
221	Narsinghpur ...	On Narbada alluvium.
222	Kotah ...	On Vindhyan sediments.

All the stations except Ambāla are on a raised part of the geoid.

6. Results.—It has been pointed out in the last two Geodetic Reports that the Hayford gravity anomaly does not show a satisfactory correlation with geological features. A large part of the anomaly is due to the deep-seated Hidden Range. After removing the effect of the Hidden Range the remaining anomaly, $g - \gamma_E$, shows some correlation with topographical features, which can be removed by applying a negative correction proportional to the average height of the topography near the stations. This indicates under compensation of the topography. Proceeding on these lines a new anomaly, $g - \gamma_F$, has been derived. (See chart XIII). This anomaly takes the place of the $g - \gamma_{E_0}$ anomaly figured in Geodetic Report Vol. VI and only differs very slightly from it.

The method by which the anomalies have been derived and the conclusions from it are being discussed in detail in Professional Paper No 27. The main conclusions, only, will be briefly summarized here.

These are:—

(*i*) Topographical and abnormal crustal densities are not compensated.

(*ii*) After removing topographical effects without compensation, the remaining anomalies are almost entirely due to deep-seated departures from normal density due to depressions and elevations of the denser layers of the crust.

(*iii*) Excluding certain major warpings of the crust, a depression is balanced by an elevation near by, so that there is no wide departure from hydrostatic equilibrium, but the depressions have a preponderating effect on gravity at the surface so that in continental areas the illusion of compensation of topographical elevations is obtained.

7. $g - \gamma_F$, and geology.—The $g - \gamma_F$ anomaly is assumed to be in most cases a direct measure of the amount of elevation or depression of the deeper layers of the crust under the gravity station within a radius of about 23 miles after removing the effect of the Hidden Range and its flanking troughs.

Chart XIII therefore shows how the crust underlying Peninsular and extra Peninsular India has been raised into "positive" areas (red) or depressed into "negative" areas (blue).

Present day topography is not necessarily elevated over a "positive" area or vice versa, but usually past denudation of the "positive" area has laid bare the lower igneous rocks, and sedimentary formations will be found over the "negative" area; so that Chart XIII distinguishes fairly successfully between igneous and sedimentary areas.

Where, however, a recent positive movement of the crust has raised up with it sedimentary formations not yet completely denuded away, the distinction between igneous and sedimentary rocks fails.

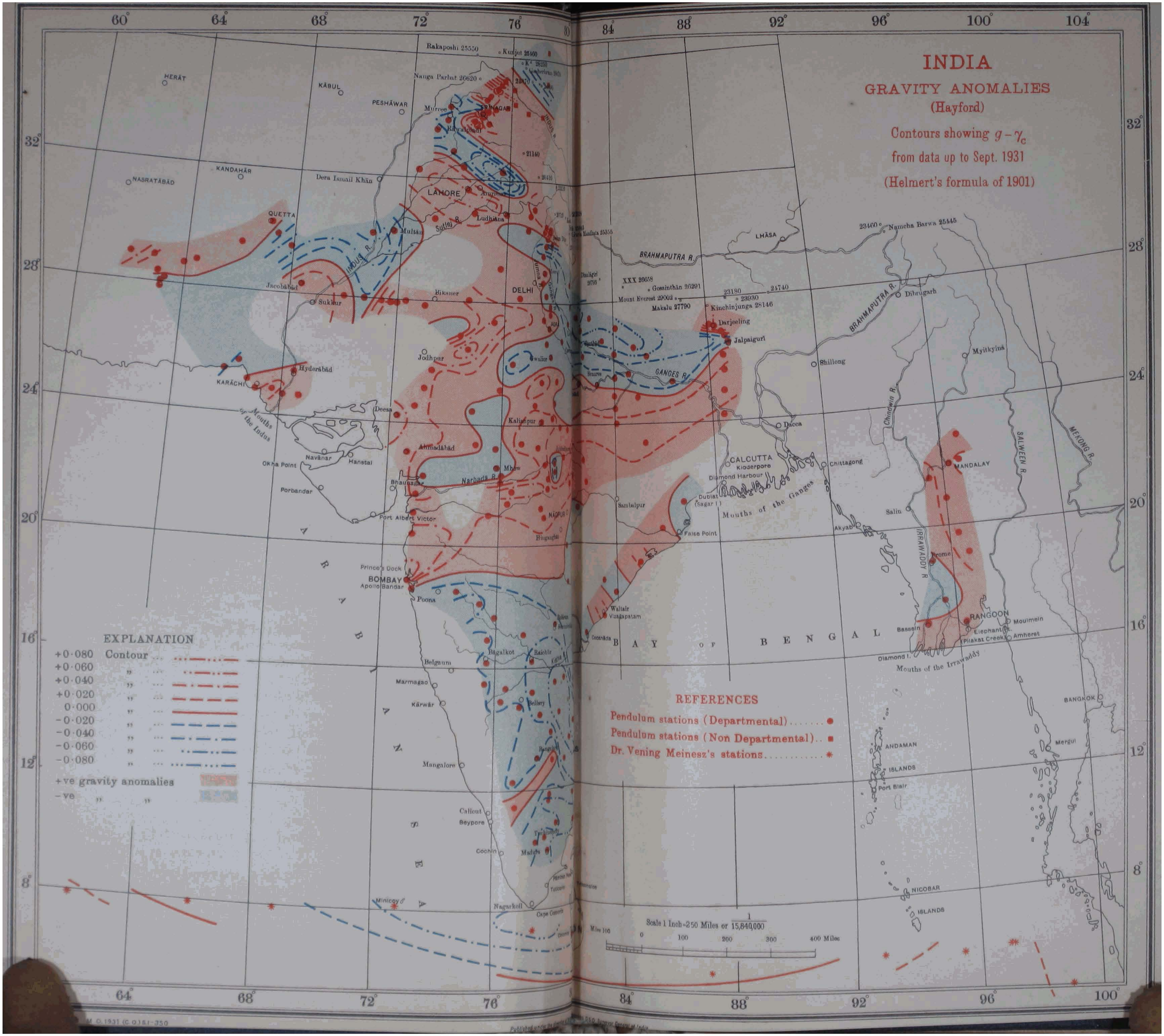

INDIA
GRAVITY ANOMALIES
(Hayford)
Contours showing $g - \gamma_c$
from data up to Sept. 1931
(Helmert's formula of 1901)
EXPLANATION
+0·080 Contour ...
+0·060 " ...
+0·040 " ...
+0·020 " ...
0·000 " ...
−0·020 " ...
−0·040 " ...
−0·060 " ...
−0·080 " ...
+ve gravity anomalies
−ve " "
REFERENCES
Pendulum stations (Departmental) .... ●
Pendulum stations (Non Departmental) .. ■
Dr. Vening Meinesz's stations .... *
Scale 1 Inch = 250 Miles or $\frac{1}{15,840,000}$
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
Multān
LAHORE
Amritsar
Ludhiāna
Sutlej R.
INDUS R.
Jacobābād
Sukkur
Hyderābād
KARĀCHI
Mouths of the Indus
Bikaner
DELHI
Jumna R.
Ganges R.
Agra
Jodhpur
Gwalior
Deesa
Kalianpur
Ahmadābād
Mhow
Narbada R.
Bhaunagar
Navānar
Hanstal
Okha Point
Porbandar
Port Albert Victor
NĀGPUR
Hinganghāt
Prince's Dock
BOMBAY
Apollo Bandar
Poona
Belgaum
Marmagao
Kārwār
Bagalkot
Raichūr
Bellary
Mangalore
Calicut
Beypore
Cochin
Madura
Tuticorin
Nagarkoil
Cape Comorin
Minicoy
Rakaposhi 25550
Kunjut 25460
K² 28250
Nanga Parbat 26620
Murree
SRINAGAR
Rawalpindi
INDUS R.
Gurla Mandhata 25355
Dhaulāgiri 26795
XXX 26658
Gosainthān 26291
Mount Everest 29002
Makalu 27790
Kinchinjunga 28146
23180
23930
24740
Darjeeling
Jalpaiguri
Benares
GANGES R.
Sambalpur
Dublat (Sagar I.)
False Point
Waltair
Vizagapatam
Cocanāda
CALCUTTA
Kidderpore
Diamond Harbour
Mouths of the Ganges
Dacca
Shillong
Chittagong
Akyab
LHĀSA
BRAHMAPUTRA R.
Dibrugarh
23460
Namcha Barwa 25445
Myitkyina
Chindwin R.
IRRAWADDY R.
SALWEEN R.
MEKONG R.
MANDALAY
Salin
Prome
Bassein
RANGOON
Moulmein
Elephant Pt.
Pilakat Creek
Amherst
Diamond I.
Mouths of the Irrawaddy
BANGKOK
Mergui
ANDAMAN
ISLANDS
Port Blair
NICOBAR
ISLANDS
ARABIAN SEA
BAY OF BENGAL
M. O. 1931 (C. O.) 51-350
Published under the direction of ... D.S.O. Surveyor General of India

Chart XIII

INDIA
GRAVITY ANOMALIES
Contours of $g-\gamma_F$
S. of I. Spheroid II

Some sedimentary formations overlying "positive" portions of the crust are:—

(*a*) Arāvalli and Delhi systems.

(*b*) Siwāliks and Purānas of Outer Himalāyas.

(*c*) Punjab alluvium.

(*d*) Tertiary and recent sediments at Karāchi, Sukkur &c.

Similarly ancient igneous rocks may be associated with a more recent negative movement of the crust. This may be the case in the extreme south of India.

The Deccan trap has, of course, flowed over both "positive" and "negative" areas.

8. The depth of the Indus alluvium.—Except at one station all gravity anomalies ($g-\gamma_C$ and $g-\gamma_F$), across the Indian desert are positive. The exception is Gorhelawāla (Station No. 207), where $g-\gamma_F = -0{\cdot}018$ cm/sec². Deflections indicate that positive anomalies will be found not far to the south, so that the "positive" area around Jacobābād and Longwāli joins on to the more easterly area and there is no deep trough under the Indus alluvium.

A single proving of the bed-rock, under the alluvium at any gravity station on this line would enable calculations of the depth of the alluvium to be made at the other stations if the deep crustal conditions are uniform.

As an illustration assume 1500 feet of light alluvium (average density 1·8) at Station No. 209.

The negative anomaly due to this is 0·017 cm/sec²; $g-\gamma_F = +0{\cdot}011$ cm/sec² so the positive anomaly due to crustal rise under this area is 0·028 cm/sec².

Hence at Gorhelawāla an anomaly equal to $-0{\cdot}046$ must be due to the alluvium, that is a depth of about 4400 feet of alluvium. This may be taken as a maximum limit of the probable depth of the alluvium at this place. At Gorhelawāla the negative anomaly is evidently associated with the negative crustal area around Sibi and Dera Ghāzi Khān; so that the positive element should be reduced. If the underlying crustal layers at Gorhelawāla have come down to normal level the same assumptions will give a depth of alluvium there of only 1600 feet.

At Station No. 208 a boring of a few hundred feet only should reach the bottom of the alluvium.

9. Gravimetric observations.—At the beginning of the field season a Gradiometer made by Messrs Oertling & Co. was received. On receipt the instrument was found to be damaged. Some screws had bent or sheared through, and the frame carrying the torsion tube etc., was buckled. This was repaired at Dehra Dūn, but in the field the instrument very soon became defective again.

Observations were made by Mr. L. D. Joshi at twenty-six stations, but the results are quite inconsistent, and are evidently marred throughout by instrumental defects.

This failure is very disappointing; a gradiometer traverse 140 miles long associated with pendulum and astrolabe observations would have been most interesting.

10. Gravity results and deflections.—There is good general agreement between gravity and deflections on the line of the traverse. This is considered in further detail in Chapter IV Section II.

TABLE 1.—*Times of vibration at Dehra Dūn, season 1930-31.*

Date	CA	AB	Mean
1930	s	s	s
October 7	0·507 9507		
,, ,, ...	9506		
,, ,, ...	9501		
,, ,, ...	9499		
,, 8		0·507 9522	
,, ,, ...		9507	
,, ,, ...		9512	
,, ,, ...		9510	
Mean ...	0·507 9503	0·507 9513	0·507 9508

Date	CA	AB	Mean
1931	s	s	s
March 29	0·507 9513		
,, ,, ...	9511		
,, 30	...		
,, ,, ...	9483		
,, ,, ...		0·507 9499	
,, ,, ...		9514	
,, 31		9499	
,, ,, ...		9513	
Mean ...	0·507 9502	0·507 9506	0·507 9504

Adopted mean times of vibration

General Mean ...	s 0·507 9503	s 0·507 9509	s 0·507 9506

TABLE 2.—*Difference between individual and mean pendulums, season 1930-31.* (The unit is 10^{-7} sec.).

Name of station	$\frac{C+A}{2}$	v	$\frac{A+B}{2}$	v
Dehra Dūn	+ 5	0	− 5	0
Longwāli	+11	+ 6	−10	− 5
Gorhelawāla	+ 5	0	− 4	+ 1
Matwāri	+ 7	+ 2	− 7	− 2
Aqilwāla	+ 6	+ 1	− 6	− 1
Charanwāla	+ 8	+ 3	− 8	− 3
Uperthal	+ 8	+ 3	− 7	− 2
Kolait	+ 6	+ 1	− 5	0
Ratangarh	+ 6	+ 1	− 6	− 1
Degāna	+ 3	− 2	− 3	+ 2
Ajmer	+ 6	+ 1	− 5	0
Nīmach	+ 6	+ 1	− 6	− 1
Ratlām *	−19	−24	+19	+24
Shujāulpur	+ 2	− 3	− 2	+ 3
Piparia	+ 4	− 1	− 3	+ 2
Pachmarhi	+ 5	0	− 4	+ 1
Narsinghpur	+ 5	0	− 4	+ 1
Kotah	+ 4	− 1	− 4	+ 1
Sawai Mādhopur	+ 2	− 3	− 1	+ 4
Ringas	− 1	− 6	+ 2	+ 7
Rewāri	+ 5	0	− 5	0
Hissār	+ 8	+ 3	− 7	− 2
Ambāla	+ 4	− 1	− 3	+ 2
Dehra Dūn	+ 2	− 3	− 2	+ 8
Mean	+ 5		− 5	

* Omitted from mean.

TABLE 3.—*Mean times of vibration and deduced values of g, season 1930-31.*

Name of Station		CA	AB	Mean
Longwāli	*s*	0·507 9273	0·507 9294	0·507 9284
	g	979·152	979·146	979·149
Gorhelawāla	*s*	0·507 9389	0·507 9398	0·507 9394
	g	979·107	979·106	979·106
Matwāri	*s*	0·507 9286	0·507 9300	0·507 9293
	g	979·147	979·144	979·145
Aqilwāla	*s*	0·507 9351	0·507 9363	0·507 9357
	g	979·122	979·119	979·120
Charanwāla	*s*	0·507 9340	0·507 9356	0·507 9348
	g	979·126	979·122	979·124
Uperthal	*s*	0·507 9334	0·507 9349	0·507 9342
	g	979·128	979·125	979·126
Kolait	*s*	0·507 9429	0·507 9440	0·507 9435
	g	979·092	979·090	979·091
Ratangarh	*s*	0·507 9415	0·507 9427	0·507 9421
	g	979·097	979·095	979·096
Degāna	*s*	0·507 9757	0·507 9763	0·507 9760
	g	978·965	978·965	978·965
Ajmer	*s*	0·507 9720	0·507 9731	0·507 9726
	g	978·979	978·977	978·978
Nimach	*s*	0·508 0258	0·508 0270	0·508 0264
	g	978·772	978·770	978·771
Ratlām	*s*	0·508 0426	0·508 0388	0·508 0407
	g	978·707	978·724	978·716
Shujāulpur	*s*	0·508 0351	0·508 0355	0·508 0353
	g	978·736	978·737	978·736
Piparia	*s*	0·508 0523	0·508 0530	0·508 0527
	g	978·670	978·669	978·669
Pachmarhi	*s*	0·508 0969	0·508 0978	0·508 0974
	g	978·498	978·497	978·497
Narsinghpur	*s*	0·508 0437	0·508 0446	0·508 0442
	g	978·703	978·702	978·702
Kotah	*s*	0·507 9972	0·507 9980	0·507 9976
	g	978·882	978·881	978·882
Sawai Mādhopur	*s*	0·507 9896	0·507 9899	0·507 9898
	g	978·911	978·913	978·912
Ringas	*s*	0·507 9611	0·507 9608	0·507 9610
	g	979·021	979·025	979·023
Rewāri	*s*	0·507 9394	0·507 9404	0·507 9399
	g	979·105	979·103	979·104
Hissār	*s*	0·507 9195	0·507 9210	0·507 9203
	g	979·182	979·178	979·180
Ambāla	*s*	0·507 9146	0·507 9153	0·507 9150
	g	979·201	979·200	979·200

TABLE 4.—*Modern gravity observations in India.*
(Additions in field season 1930-31).

No.	Sheet No.	Station	Date	Height	Latitude N.	Longitude E.	g	$g-\gamma_A$	$g-\gamma_B$	$g-\gamma$
				feet	° ′ ″	° ′ ″	*cm/sec²*	*cm/sec²*	*cm/sec²*	
206	39 L	Longwāli ...	5 11 30	243	28 02 05	70 00 28	979·149	+ ·001	− ·007	+·0
207	40 I	Gorhelawāla ...	24 11 30	319	27 59 23	70 44 26	979·106	− ·031	− ·042	−
208	40 M	Matwāri ...	8 12 30	356	27 57 12	71 25 24	979·145	+ ·014	+ ·002	+
209	40 M	Aqilwāla ...	15 12 30	414	27 53 40	71 44 42	979·120	− ·001	− ·015	+
210	40 M	Charanwāla ...	21 12 30	443	27 53 37	71 57 17	979·124	− ·002	− ·017	+
211	45 A	Uperthal ...	29 12 30	460	27 59 57	72 14 42	979·126	+ ·001	− ·014	+
212	45 A	Kolait ...	6 1 31	709	27 50 05	72 57 20	979·091	+ ·001	− ·023	−
213	44 L	Ratangarh ...	10 1 31	1030	28 04 20	74 37 05	979·096	+ ·019	− ·016	+
214	45 J	Degāna .	13 1 31	1112	26 53 59	74 19 25	978·965	− ·018	− ·055	−
215	45 J	Ajmer ...	20 1 31	1587	26 28 18	74 38 42	978·978	+ ·071	+ ·018	+
216	45 L	Nīmach ...	28 1 31	1602	24 27 50	74 50 48	978·771	+ ·006	− ·048	−
217	46 M	Ratlām ...	31 1 31	1614	23 20 02	75 03 03	978·716	+ ·027	− ·027	−
218	55 A	Shujāulpur ...	5 2 31	1480	23 22 46	76 43 32	978·736	+ ·032	− ·018	+
219	55 J	Piparia ..	10 2 31	1102	22 45 08	78 21 22	978·669	− ·031	− ·068	−
220	55 J	Pachmarhi ..	13 2 31	3498	22 28 23	78 25 42	978·497	+ ·040	− ·076	−
221	55 N	Narsinghpur ...	17 2 31	1180	22 56 37	79 12 40	978·702	− ·001	− ·041	+
222	45 O	Kotah ...	25 2 31	823	25 12 09	75 53 15	978·882	− ·007	− ·035	+
223	54 B	Sawai Mādhopur	28 2 31	871	26 01 05	76 21 36	978·912	− ·030	− ·059	−
224	45 M	Rīngas ...	4 3 31	1573	27 22 07	75 33 47	979·023	+ ·049	− ·004	+
225	53 D	Rewāri ...	7 3 31	800	28 11 56	76 36 30	979·104	− ·004	− ·031	+
226	44 O	Hissār ...	11 3 31	694	29 09 14	75 43 18	979·180	− ·011	− ·034	+
227	53 B	Ambāla ...	17 3 31	888	30 20 13	76 50 00	979·200	− ·065	− ·095	−

The anomalies are given with reference to Helmerts' formula of 1901,

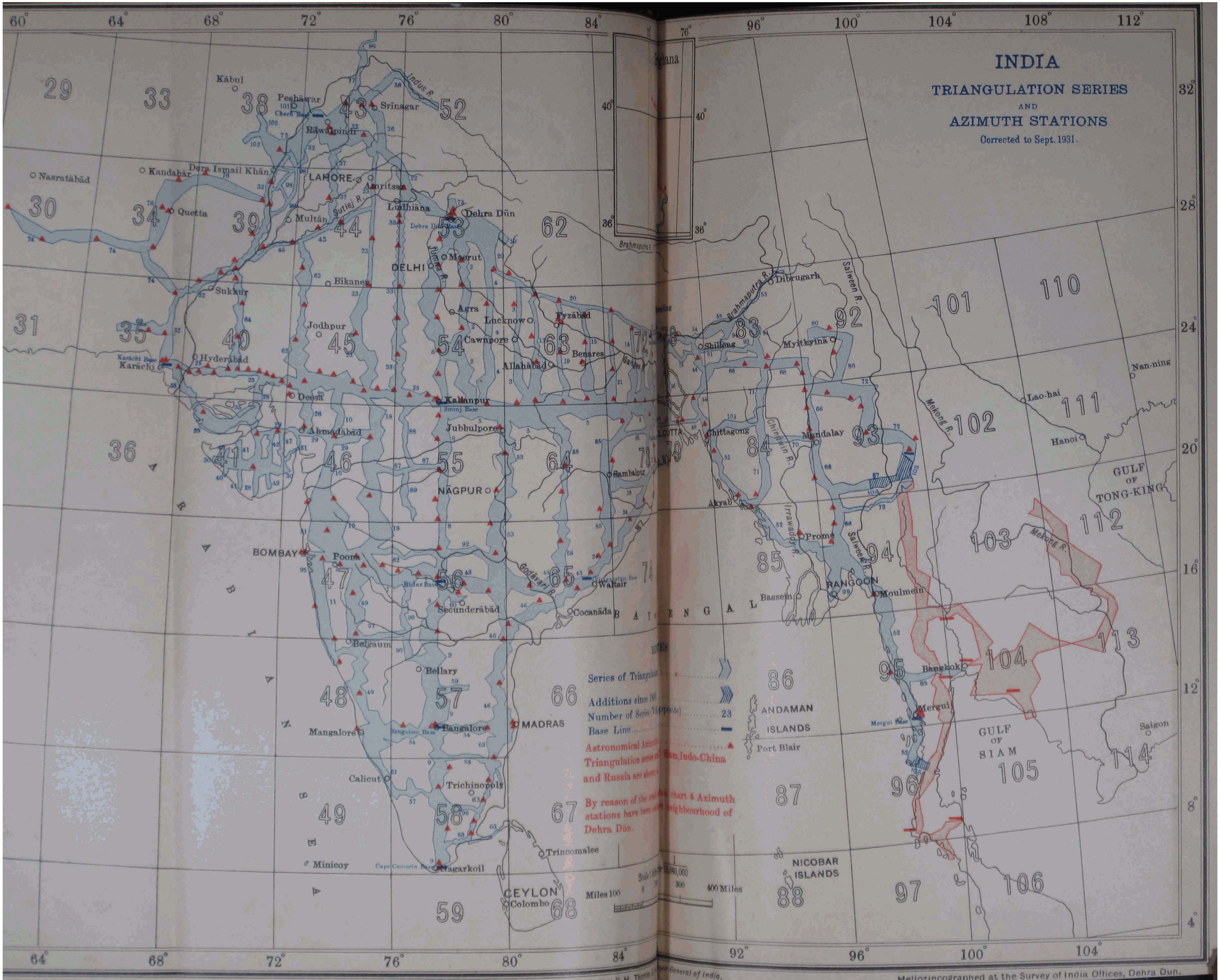
$$\gamma_0 = 978{\cdot}030\,(\,1 + 0{\cdot}005\ 302\,\sin^2\phi - 0{\cdot}000\ 007\,\sin^2 2\phi\,)\ \text{cm/sec}^2$$

Corrigenda. Supplement to Vol. VI, *page* lxiv.

Station No. 119, under $g-\gamma_c$ *for* —·013 *read* —·019.

Station No. 125, „ „ *for* —·062 *read* —·072.

NOTE. This table is the first addendum to the list of gravity stations given in the Supp to Geodetic Report Vol. VI. Addenda to the list of deflection stations are given on pp. 68



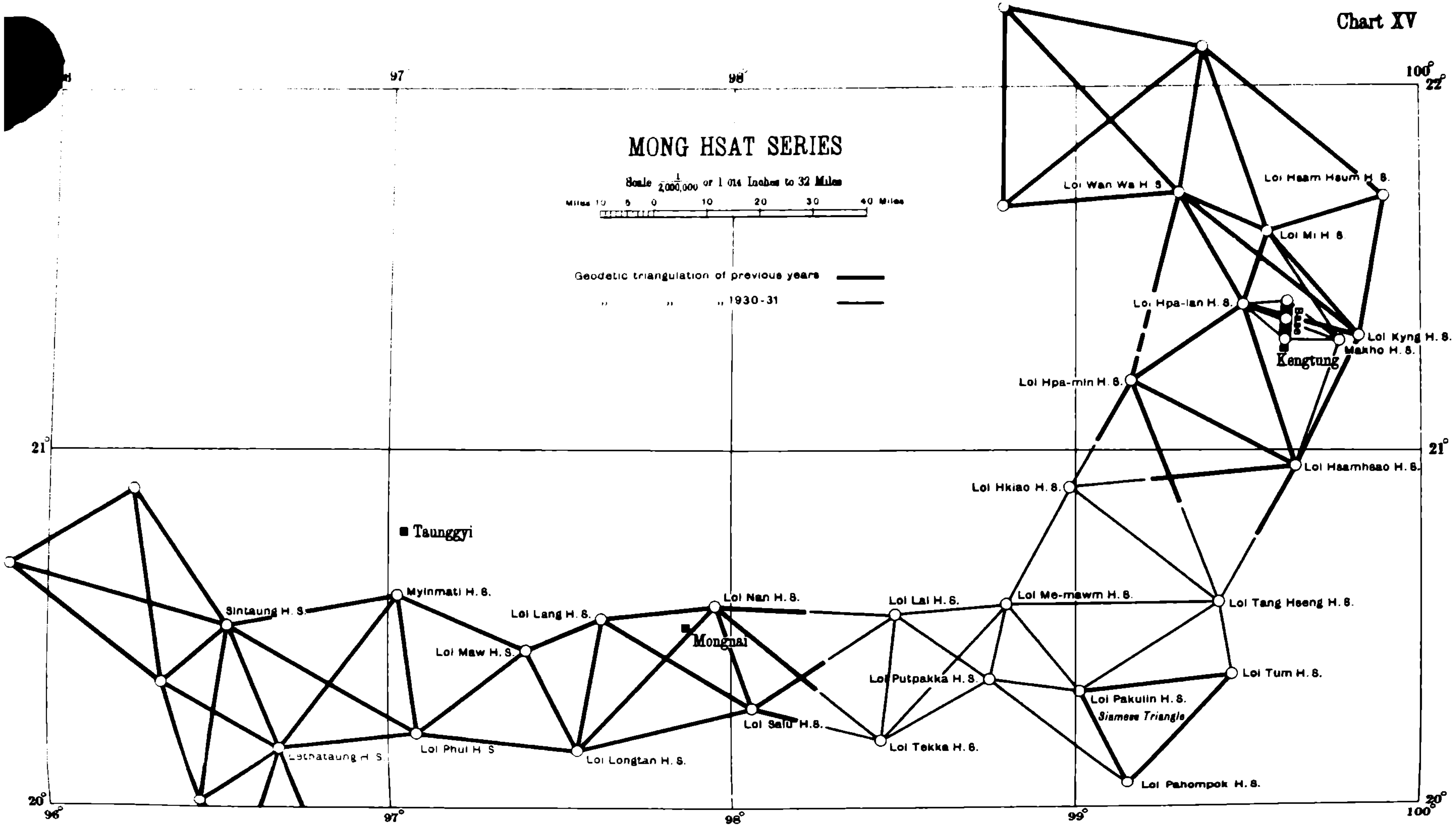
INDIA
TRIANGULATION SERIES AND AZIMUTH STATIONS
Corrected to Sept. 1931.

M.D.1931 (C.O)S.I.-375

Published under the direction of Brigadier R. H. Thoma eyor General of India,
1931

Heliozincographed at the Survey of India Offices, Dehra Dun.

Chart XV


MONG HSAT SERIES
Scale 1/2,000,000 or 1.014 Inches to 32 Miles
Miles 10 5 0 10 20 30 40 Miles
Geodetic triangulation of previous years
" " " 1930-31
Loi Wan Wa H. S.
Loi Haam Haum H. S.
Loi Mi H. S.
Loi Hpa-lan H. S.
Base
Loi Kyng H. S.
Makho H. S.
Kengtung
Loi Hpa-min H. S.
Loi Haamhsao H. S.
Loi Hkiao H. S.
Taunggyi
Myinmati H. S.
Sintaung H. S.
Loi Lang H. S.
Loi Nan H. S.
Mongnai
Loi Lai H. S.
Loi Me-mawm H. S.
Loi Tang Hseng H. S.
Loi Maw H. S.
Loi Putpakka H. S.
Loi Tum H. S.
Loi Pakulin H. S.
Siamese Triangle
Loi Salu H. S.
Lethataung H. S.
Loi Phui H. S.
Loi Longtan H. S.
Loi Tekka H. S.
Loi Pahompok H. S.
97°
98°
99°
96°
100°
22°
21°
20°

CHAPTER VI

TRIANGULATION AND BASE MEASUREMENT

BY CAPTAIN G. BOMFORD, R.E.

1. **Summary.**—The season's programme consisted of primary triangulation in Burma with two detachments, and of the measurement of a base-line at Kengtung. The programme was satisfactorily completed with the result that the Siamese primary triangulation is now connected to the Mong Hsat and Great Salween Series in latitude 20° 30′, and with the Burma Coast Series in latitude 10° 30′. The party suffered a great loss in the death of Lieut. I. M. Cadell, R.E., from pneumonia at Loi Hkiao H.S. in the Southern Shan States on 27th Dec., 1930.

Lieut. Cadell was in charge of the party until his death, when he was replaced by Captain G. Bomford, R.E.

Table 1 gives a summary of the work done on these series, and also details of the Chittagong Series which have not previously been published.

2. **No. 1 Detachment.**—No. 1 Detachment under the officer-in-charge of the party undertook the completion of the Mong Hsat and Great Salween Series and the base measurement at Kengtung. The detachment left Dehra Dūn on 4th Sept., and started work at Loi Tekka on 4th Oct. The work was continued towards the east, as far as Loi Tum and Loi Pakulin, at which the Siamese had observed in 1928-29. From these two stations the series turned north to connect with last season's triangulation near Kengtung.

Lieut. Cadell fell sick after completing Loi Tang Hseng H. S. He managed to reach Loi Hkiao on 18th Dec., but died on 27th Dec. He is buried in the dak bungalow compound at Mong Ping about 40 miles to the north.

The posting of a new officer-in-charge from India inevitably caused some delay, and the observations at Loi Hkiao were not completed until 29th January. The beginning of February, however, gave a spell of exceptionally fine weather, and the remaining seven stations were completed by 22nd Feb., after which the base measurement was begun (see para 6).

TABLE 1.—*Primary Triangulation. 1928-31.*

	Chittagong Series	Mong Hsat Series	Part of Great Salween Series	Part of Burma Coast Series
Season	1928-29-30	1929-30-31	1929-30-31	1930-31
Number of new stations built	1	7	8	4
Number of stations observed at	18	16	11	8
Length of triangulation in miles	140	184	75	50
Area in square miles ...	1930	4220	2300	1006
Mean length of sides in miles	21	27	29*	22
Number of triangles observed	20	24	21	14
Average triangular error ...	0″·63	0″·62	0″·97	0″·32
Maximum triangular error ..	2″·07	2″·09	2″·80	0″·64
Value of m ..	0·453	0·441	0·682	0·205
Value of M	0·45	0·38	0·58	0·19
Value of p	2·18	1·67	3·04	1·29
Value of P	2·09	1·35	2·41	1·17
Order of merit	22*b*	17A	27A	1A
Instruments used ...	Wild No. 59	12″ No. II; Wild No. 130	Wild No. 130	12″ No. II

* Excluding base-net.

The theodolite used was Wild 5½-inch No. 130. Details of its behaviour are given in para 4. On the whole it worked very well, and the programme would certainly not have been completed if a 12-inch theodolite had had to be used. After correction for the effects of back-lash in the horizontal circle (see para 4), which gave trouble in the middle of the season, the average triangular error of 30 triangles is 0″·81.

During the first half of the season, observations were made about equally to helios and to lamps, but during the second half helios were almost exclusively used. A curious effect was observed at the three Kengtung Base stations. The rays along this base graze within 10 or 20 feet of the ground throughout their length, and a helio was consequently a very unattractive mark, large, in constant movement and sometimes vertically duplicated. At night the appearance of a small lamp was both sharp and steady. Nevertheless it was found that observations made at night were completely unreliable, the lamps drifting from side to side up to as much as 5 or even 10 seconds from the mean, while in the afternoon careful bisection of the helio's vibrations gave results which were quite reasonably accordant, although repetitions were naturally much more frequent than is found necessary under more favourable circumstances. The early morning gave results similar to the night, while between about 11 a.m. and 2 p.m. the distortion and movement of the helio were too great for work to be possible.

BURMA COAST SERIES

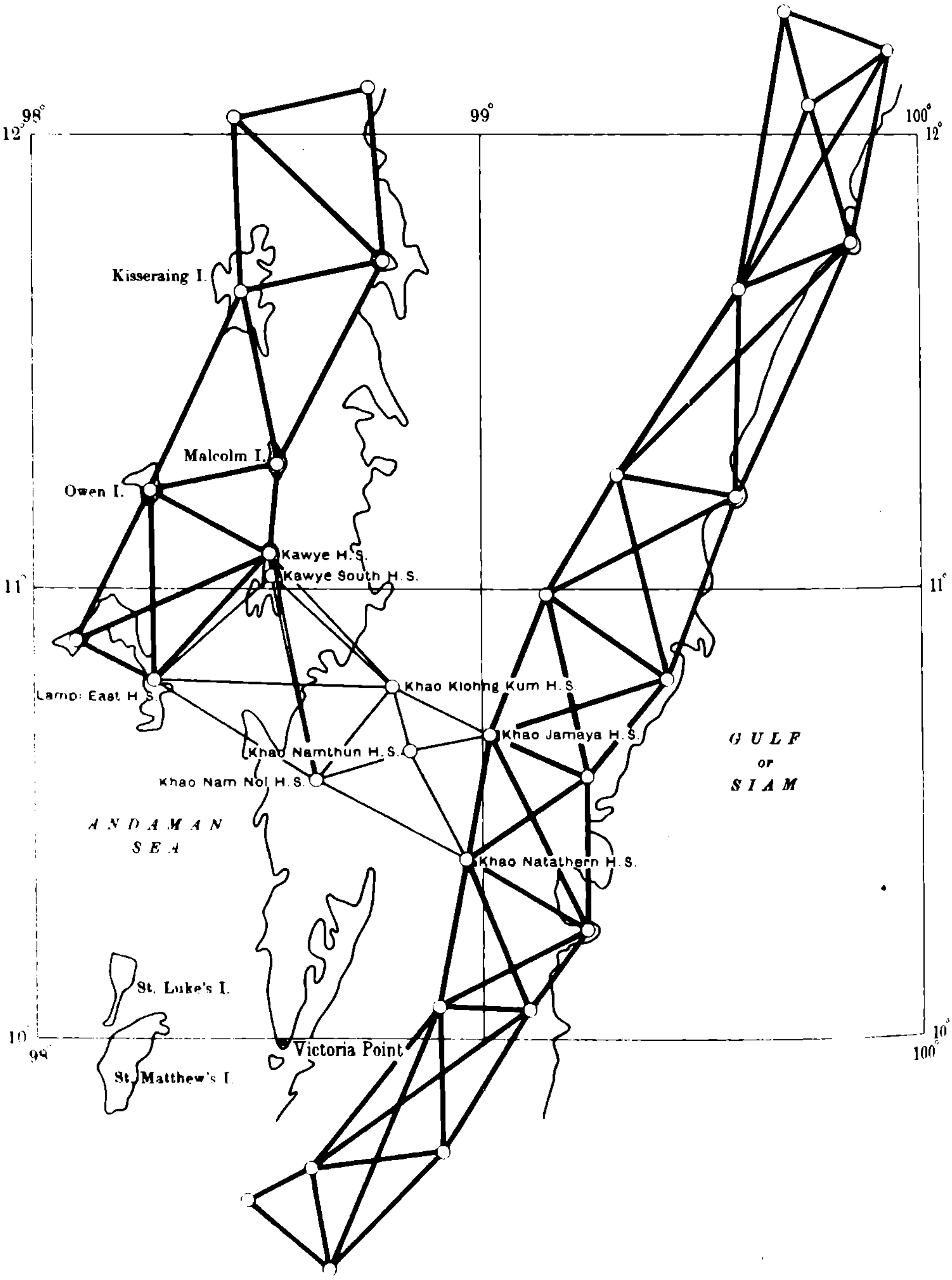
Chart XVI

Scale $\frac{1}{2,000,000}$ or 1·014 Inches to 32 Miles

Miles 10 5 0 10 20 30 40 Miles

Geodetic triangulation of previous years ▬

,, ,, ,, 1930-31 —



Astronomical latitudes and azimuths were observed at five stations near Kengtung (see para 5). It is intended to observe longitude at Kengtung Base South S at some future date, and so to form a Laplace station.

The health of the detachment was poor in the early part of the season, but it was good during January, February and March, which were dry and healthy. One khalāsi and one private servant died. From the point of view of triangulation the detachment was favoured with much better weather than during the previous year. Work was very seldom interrupted by clouds, and except that lamps were barely visible in February no interruption was caused by haze. Permanent mule transport (Chinese) was employed and was very satisfactory, the mules reaching the tops of all the hills except Loi Hpa-lan. Coolies and essential supplies were generally obtainable without difficulty.

3. **No. 2 Detachment.**—No. 2 Detachment under Mr. M.N.A. Hashmie, B.A., undertook the reconnaissance and observation of a junction between the terminal stations of the Burma Coast Series in latitude 10° 30′ and the neighbouring stations of the Siamese primary triangulation. The detachment left Dehra Dūn on 4th Sept., 1930 and started observations at Khao Namnoi H.S. on 23rd Nov. After completing Khao Namnoi H. S. and Lampi H. S., it was found that the site of a new station Khao Klohng Kum was unsatisfactory, with the result that it had to be rebuilt on an adjacent hill, and the two stations already observed had to be revisited. After this delay observations proceeded well, and the work was completed on 10th March. Eight stations were observed at, including a satellite station south-east of Kawye H. S., where it was feared that a grazing ray might suffer from horizontal refraction. The theodolite used was 12-inch No. II. Good results were obtained, the average triangular error of 14 triangles being $\pm 0''\cdot32$. Observations were made to helios and lamps in about equal proportions. It was noticeable that distant helios seen over the sea appeared much more steady than when viewed at a similar distance over land.

The health of the detachment was poor, there being much fever and some cases of beri-beri. One daffadār and five khalāsis died. During October, November and December 1930 rain and cloud caused continual interruption, but the weather improved during January and February. The very thick jungle makes for slow progress, and was the cause of the original misplacing of Khao Klohng Kum H.S. Transport is by coolies, who are obtainable locally but only at a heavy cost. Essential supplies, except water and firewood, have to be imported.

One of the stations built during the season, and two of the other stations visited, were in Siamese territory. Arrangements had previously been made with the Siamese authorities, who gave all possible assistance to the detachment.

4. Wild theodolite.—The Wild theodolite used by No. 1 Detachment started the season well. The triangles of the first two quadrilaterals showed no traces of the tendency to measure too small, which had caused such trouble during 1929-30, the triangular errors being positive and satisfactory. The trouble then started again, and triangular errors of over two seconds resulted. Later in the season this tendency was remedied by a change in the observing programme, while the application of corrections deduced from the observations themselves (as explained below) has made it possible to go a long way towards rectifying the observations made between the onset of the trouble and the change of programme.

There is little doubt that the cause of this persistent under measurement during the last season was due to a taking up of back-lash in the fixing of the graduated circle during the first angle measured after any change of face, swing, or zero. After any such change it was always the practice to turn the telescope at least 180° in the direction of swing* before intersecting the first station, but it is evident that this is not sufficient. The condition of the theodolite is clearly illustrated by the abstract of angles observed at Loi Hsamhsao, shown on the opposite page. On the evening of 4th Feb., the angle was measured once on each face on each zero, as shown in the first line of the abstract. These measures may be called L_1 & R_1. On the following morning the angle was measured twice on face left and twice on face right on each zero, the two measures on each face being consecutive, without any break in the swing of the theodolite. These measures (L_2, L_3, R_2 and R_3) are shown in the second and third lines of the abstract. The means in the last column show that L_2 and R_2 are in good agreement with L_1 and R_1, but that L_3 and R_3 average about 1″·8 larger. The increase takes place in each separate zero. Further examination of the angle-book shows that in every single case the L_3 circle reading of the first station observed is greater than the L_2 reading, while the R_3 circle reading is less than the R_2, indicating that during the first 360° the graduated circle has slipped in the direction of swing twenty times out of twenty. The average slip is 2″·1.

It is clear that the measures L_2 and R_2 can be considerably improved by applying a correction for this slip, the only doubt being what proportion should be applied to the angle of the triangle (40°), and how much to the complementary angle (320°). Examination of the angle-book readings of the *second* station observed in each round shows that the slip in the 360° immediately following its intersection averaged only 0″·6, and that the change was in the direction of swing only 13 times out of 20: which indicates that comparatively little slip took place after the intersection of the second station. It therefore seems best to apply the whole of the slip to the first angle measured, and to assume that no slip occurred subsequently. Neither assumption is likely to be perfect, but the first errs in the direction of making the accepted mean value of the angle too large, while the second tends to make it too

---

[*] The direction of swing has been regulated by the rule—Face right, swing right, and vice versa.

Abstract at Loi Hsamhsao H.S.

Seconds

Zero	0°		18°		36°		54°		72°		90°		108°		126°		144°		162°		Means
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	
L_1 & R_1	03·6	03·3	06·4	02·0	04·1	05·7	05·1	04·4	05·9	05·5	09·6	07·1	07·4	06·2	04·5	03·9	03·1	04·1	02·6	02·8	**04·87**
L_2 & R_2	05·9	05·0	05·6	07·5	04·3	09·0	06·6	05·0	08·1	06·1	07·5	06·3	08·0	05·8	06·1	03·4	04·2	03·2	02·4	00·9	**05·55**
L_3 & R_3	05·2	08·1	06·7	07·4	04·4	09·8	06·3	08·4	09·2	07·2	08·8	11·1	09·2	08·7	06·2	05·9	05·6	04·2	06·0	02·1	07·03
Mean ...	05·18		05·93		06·22		05·97		07·00		08·40		07·55		05·00		04·07		02·80		

General Mean 39° 37′ 05″·81

small. A certain amount of cancellation of the resulting errors may therefore be expected.

At the stations preceding Loi Hsamhsao the programme of observation on each zero was L_1 R_1 R_2 L_2 L_3 R_3. Following the rule that all slip is to be applied to the first angle of any swing, it is seen that the first angles measured on L_1 and R_3 have to be totally rejected, since no measure of the slip is available: R_1 and L_2 duly receive the correction: and R_2 and L_3 require no correction, having been immediately preceded by another round on the same face. Angles other than those between the first and second stations of each swing require no correction at all. Abstracts have been prepared on these lines* and Table 2 shows the resulting improvement in the triangular errors in the part of the series observed while slip was occurring. The great reduction in the mean error, taken with regard to sign, is very noticeable. The mean taken with regard to sign has, of course, no significance as a measure of the precision of the work, but it shows up the systematic slip in the uncorrected angles.

TABLE 2.—*Result of correcting for slip of lower plate.*

	Triangle	Triangular Errors	
		Before correction for slip	After correction for slip
1	Putpakka, Me-mawm, Pakulin	−0″·34	+0″·17
2	Me-mawm, Pakulin, Tang Hseng	−2·21	−1·22
3	Tang Hseng, Pakulin, Tum .. .	−1·06	−0·08
4	Putpakka, Pakulin, Pahompok	−1·52	−0·69
5	Tum, Pakulin, Pahompok	+0·20	+1·03
6	Tang Hseng, Me-mawm, Hkiao	−1·37	−0·66
7	Tang Hseng, Hkiao, Hsamhsao	+0·46	+1·23
8	Tang Hseng, Hkiao, Hpa-min	−1·14	−0·32
9	Tang Hseng, Hpa-min, Hsamhsao	+0·74	+1·21
10	Hsamhsao, Hkiao, Hpa-min	−0·86	−0·35
11	Hsamhsao, Hpa-lan, akho	−2·40	−0·83
12	Makho, Hpa-lan, Mi	−2·63	−1·85
	Mean with regard to sign ...	−1·01	−0·20
	Mean without regard to sign ...	1·24	0·80

At the stations visited after Loi Hsamhsao the order of observation was changed to L_1 L_2 L_3 R_1 R_2 R_3, in consequence of which no angle has to be rejected, even if slip occurs. Great care was taken to ensure continuity of swing during the three measures on each face, and after any change of face or zero the theodolite was swung round several times in the direction of swing, in the hope of taking up all back-lash. The number of preliminary revolutions was eventually increased to as many as 10 or 15, and the good

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* At the early stations at which slip was not occurring, and where small positive triangular errors were obtained, there has been no need to do this. Nor have revised abstracts been prepared for the last three stations, at which slip was fully eliminated by very rigorous preliminary rotation of the telescope.

central closure at Kengtung Base Centre S. (0″·03) indicates that this was effective.

At the last seven stations zero was changed 9° when face was changed. Observations were thus made on 20 zeros, three face left measures on 10 zeros, and three face right on 10 others. The change of zero takes very little time and it was thought desirable in order to obtain fuller cancellation of graduation error.

5. Astronomical observations.— Astronomical latitudes and azimuths were observed at the three Kengtung Base stations and at the two stations on the hills immediately overlooking the base. The large deviations of the vertical which occur in this part of India, combined with the steep elevations of the rays connecting the base to the surrounding hills, result in an appreciable correction to horizontal angles due to the dislevelment of the theodolite. In the case of the angle Base North—Hpa-lan—Makho this correction amounts to 0″·95.

The latitude programme consisted of two north and two south circum-meridian stars, Polaris out of meridian being used as one of the north stars. The probable error of the mean at any one station is about 0″·8. Azimuth was obtained by observation to Polaris, and the programme consisted of one face left and one face right on each of ten zeros. Observations were not confined to the hours near elongation. The average probable error of the mean at each station was ± 0″·5. These latitude and azimuth programmes were intended to measure the deflection correct to 5″, for which they were certainly adequate, although in the absence of any near Laplace station, doubt in the geodetic azimuth admits of rather greater uncertainty in the prime vertical deflection. The results are given in Chapter IV of this report, para 8 and Table 4.

The azimuth at Kengtung Base South S. was more carefully observed with a view to the later formation of a Laplace station. Polaris was observed three times on each face on each of 10 zeros. On 5 zeros Loi Makho H.S. was used as the referring mark, and on 5 zeros Loi Hpa-lan H.S., with the following results :—

Azimuth of Loi Makho H.S.	...	269°	14′	55″·1	±0″·5
Azimuth of Loi Hpa-lan H.S.	...	130	27	21 ·3	±0 ·5
Difference	...	138	47	33·8	
Direct measure of angle *	...	138	47	32·8	
Discrepancy	...			1·0	

The probable errors given above were derived from the accordance of the different zero means. The probable error of the general mean may be taken to be ±0″·4.

Azimuth observations in the Survey of India have hitherto been made with a long programme utilizing circum-polar stars nearly at elongation. The use of Polaris at all hours results in a much lighter programme, which is of course further lightened by the use of the Wild theodolite. The observation of the careful azimuth at Kengtung Base South S. including the necessary time observations (two nights), involved only five hours of work.

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* After grinding figure.

6. Kengtung Base.—The base-line is 7½ miles long and lies roughly north and south through the centre of Kengtung plain. It is divided into two halves by Kengtung Base Centre Station, and each half is divided into four sections of approximately 1 mile each. The base is sensibly straight throughout, and there is no correction for alignment. The north terminal is on the slopes of the hills bounding the plain, about 24 feet above the adjacent paddy fields. The centre station and south terminal are in the paddy fields, and are brick towers 4 and 9 feet high respectively. The line of the base is almost continuous paddy field interrupted only by a few streams with bamboo jungle on either side.

The detailed alignment of the base, and all the preparations for its measurement, were carried out by Mr. L.R. Howard. Mr. Howard prepared the stations and intermediate marks, cleared a line about 20 yards wide along the base, and put out carefully aligned pegs at 24-metre intervals over which the tripods were afterwards set up. When the pegs fell in small streams or badly broken ground, platforms were built up to a convenient level. Earth ramps were also constructed sloping gently up to the centre and terminal stations.

The measurement of the base was carried out by Captain Bomford and Mr. P.K. Chowdhury, reading the two ends of the wires, assisted by a recorder and about 20 khalāsis. The tripods were set up in advance by Mr. Howard with about 15 khalāsis. If personnel had been available another officer would have been employed on spirit-levelling along the pegs over which the tripods were plumbed. As this was not possible the pegs were levelled on off-days before and after measurement, any which appeared disturbed[*] being checked by Mr. Howard while setting up the tripods.

Six wires were employed in the measurement; Nos. 249 and 252 as standards against which the field wires were compared in camp every morning; Nos. 243 and 247 for the south to north measurement; and Nos. 244 and 248 for north to south. At each bay four scale readings were made on each wire, with additional readings if the range of variation exceeded 0·3 mm. When comparing the field wires with the two standard wires ten readings were made, the observers changing ends after the first five. Air temperatures were recorded at each bay by means of a clockwork aspiration thermometer, and the temperature of the wires was assumed equal to that of the air[†]. Heights of tripods were obtained by measuring up from the spirit-levelled pegs with a tape, except that where the slopes were steep, spirit-levelling was carried out to staves placed on the tops of the tripods themselves. The

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[*] There were actually two pegs at every 24-metres, with a wooden slat nailed across their tops. Any considerable movement of a peg was betrayed by the dislevelment and splitting of the slat.

[†] That this assumption is not grossly in error was proved by the fact that wires exposed to the sun felt cool to the cheek when the air temperature was 92° F. This positively limits the error to 70° F., for which the mean temperature correction is about 1 : 2,000,000.

wires were "exercised" for an hour before work every day, being suspended under their usual tension and under light tension for alternate periods of about 10 minutes each.

The rate of work started at 60 bays a day (nearly 1 mile) and increased to 125 bays a day as the squad gathered experience. The total time required for measurement, including levelling and the repetition of two sections was 16 days. This of course excludes the clearing and aligning previously carried out by Mr. Howard, which occupied about 2 months.

The lengths of the wires were determined in the Observatory Section before and after the field season (see Chapter II, para 1), during which interval the wires maintained a satisfactory constancy of length, the four wires used for the actual work holding their lengths better than the two field standards (see Chapter II, para 1 *j*). In these four wires the average change was 1 : 2,500,000, and the mean of the two observatory determinations has consequently been accepted for them, ignoring the daily comparisons. The wires were provided with certificates of coefficient of expansion as determined by the Bureau International des Poids et Mesures in 1908, but the systematic changes in the differences between the pairs of field wires between the cold of the morning (13°C) and the heat of midday (33°C) soon showed that these values were no longer applicable. Provisional values were obtained in the field by the careful measurement of 10 bays in the early morning and again at midday, which have been confirmed by observations made on the 24-metre comparator in Observatory Section (see Chapter II, para 1 *c*).

The lengths (in metres) finally obtained for the different sections of the base are :—

		Wire 243	Wire 244	Wire 247	Wire 248	Mean
Section	1 ..	1487·938	1487·940	1487·940	1487·939	1487·939
	2 ...	1488·277	1488·284	1488·280	1488·282	1488·281
	3 ...	1440·322	1440·325	1440·324	1440·325	1440·324
	4 ...	1570·959	1570·960	1570·961	1570·960	1570·960
Total South Half ...		5987·496	5987·509	5987·505	5987·506	5987·504
Section	5 ...	1512·513*	1512·513	1512·515*	1512·512	1512·513
	6 ...	1512·350†	1512·354†	1512·352†	1512·353†	1512·352
	7 ...	1512·178	1512·182	1512·181	1512·181	1512·181
	8 ...	1199·225	1199·223	1199·226	1199·224	1199·225
Total North Half ...		5736·266	5736·272	5736·274	5736·270	5736·271

Mean total measured from S. to N. (243 & 247) =11,723·772 metres
Mean total measured from N. to S. (244 & 248) =11,723·778 metres
GENERAL MEAN =11,723·775 metres

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* Revised values. The first measures were 1512·498 and 1512·504. This was the first day's work, and some blunder evidently occurred.

† The mean of ·349 and ·350, ·355 and ·353, ·353 and ·351, ·355 and ·352 respectively. The first measure appeared discordant and was repeated. The means of both measures have been accepted.

The discrepancy of 0·006 metres between the two measures amounts to 1 : 2,000,000 of the total length of the base. The ratio of the lengths of the north and south halves of the base is also given by the angles observed at Loi Hpa-lan and Loi Makho. The ratio derived from triangulation differs by 1 : 360,000. from that given by direct measurement. This discrepancy can readily be attributed to errors in the (rather small) angles on which the triangulated ratio depends, and the direct linear measures have been accepted as correct.

The value given above for the length of the base is in metres as given by the silica and nickel 1-metre standards (1931 N.P.L. Certificates). Conversion to Indian feet* (tenths of old standard Bar A), in terms of which the lengths of all other Indian bases are expressed, is effected by the relations :—

1 standard yard = 0·914 399 20 metres.
1 Indian foot = 0·333 331 886 standard yards.†

The resulting length of the base at ground level is 38,464·03 Indian feet.

For the reduction to sea-level it is necessary to consider the height of the base above the Everest spheroid. The mean height above the geoid, as given by spirit-levelling, is 2550 feet, but in Burma the geoid is considerably elevated above Everest's spheroid, on account of the axes of the latter being smaller than those of the mean figure of the Earth. The number of deflection observations available is not sufficient for an accurate determination of the form of the geoid in Burma, but a sufficiently accurate figure for the geoidal rise at Kengtung will be obtained by assuming that the form of the geoid is well represented by the International spheroid, so oriented as regards deflections at the origin as to make the best possible fit with the geoid in India. The separation between this spheroid and Everest's spheroid at any place is easily calculated. At Kengtung it is 250 feet, so that the spheroidal height of Kengtung may be taken as 2800 feet.

The length of the base reduced to sea-level (spheroidal) is therefore

38,458·85 Indian feet
or 4·584 9964 log feet.

This figure is believed to be undoubtedly correct to 2 : 1,000,000 or 8 in the 7th decimal of the log. The probable error is of course much less, (see Chapter II, para 1 *k*). The triangulated value in terms of the Mong Hsat Series is 4·585 0036 and in terms of the Great Salween 4·584 9893.

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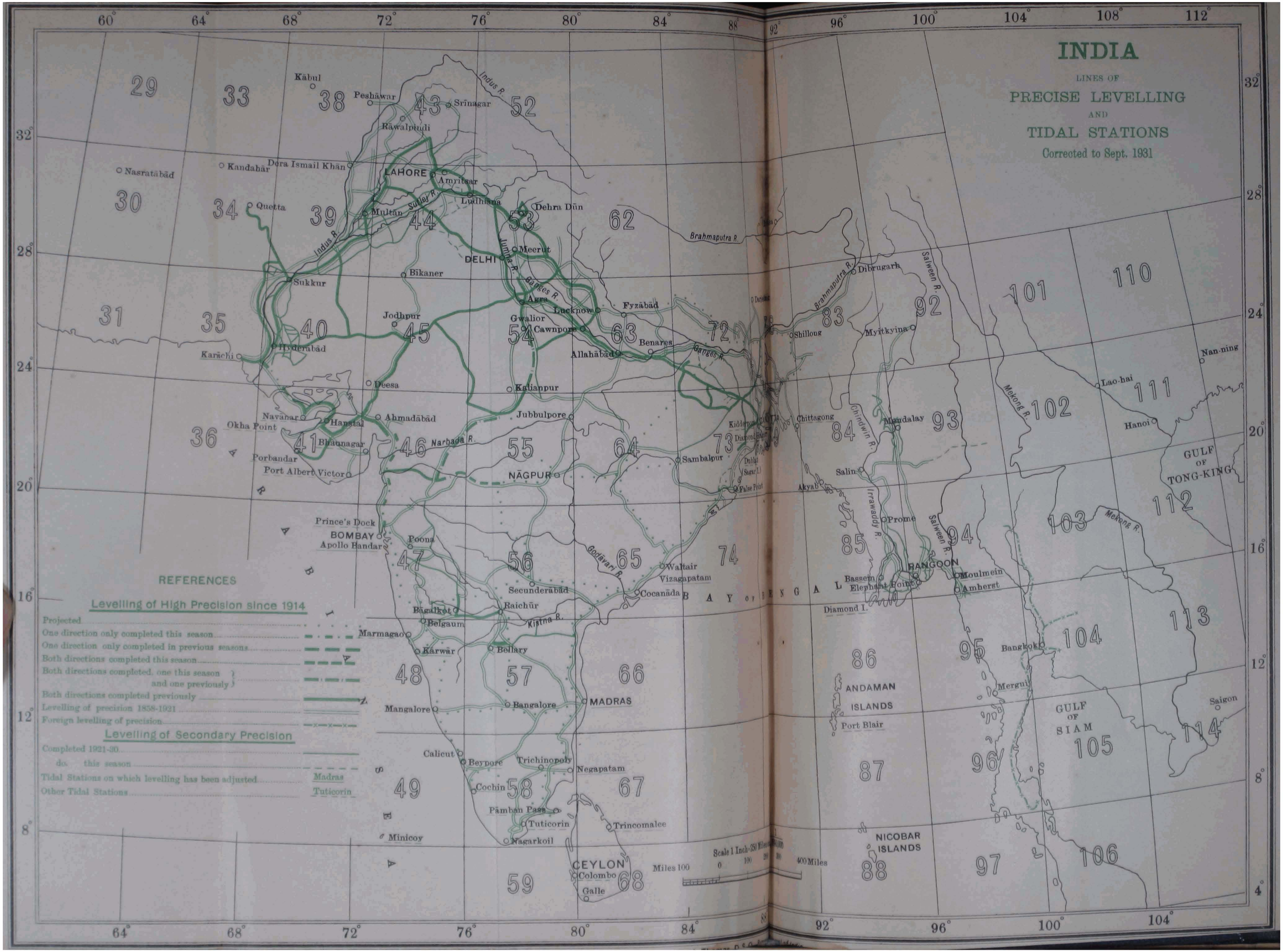
* See G.T.S. Vol. I, page 101.

† See "Supplement" to Geodetic Report Vol. VI.



INDIA

LINES OF

PRECISE LEVELLING

AND

TIDAL STATIONS

Corrected to Sept. 1931

CHAPTER VII

LEVELLING

BY D. H. LUXA

1. **Organization.**—Eight detachments were formed and employed as follows:—3 on high precision levelling, 4 on secondary levelling, and 1 on tertiary levelling. Except for one high precision detachment and the tertiary detachment all the others were employed throughout the season.

Secondary levelling was carried out for the Bhakra Dam Project (Punjab Irrigation), Bihār and Orissa Flood Area, East Indian Railway and Burma Railway. The lines Tīnpahār-Pīrpainti-Purnea and Taunggyi-Kengtung were run for departmental purposes.

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

High precision levelling in fore direction	264 miles	(289 gross).*
,, ,, ,, ,, back ,,	468 ,,	(537 ,,).
,, ,, ,, ,, both directions	232† ,,	(270 ,,).
Equivalent total in one direction ...	964 ,,	(1096 ,,).
Secondary levelling	1431 ,,	(1574 ,,).
,, ,, (revision) ...	38 ,,	(39 ,,).
Tertiary ,, ,, ...	600 ,,	(600 ,,).

3. **Work of detachments.**—*No. 1 detachment* under Mr. J. N. Kohli did the following high precision levelling, his total out-turn being 465 miles (505 gross) with 51 miles of relevelments (31% ‡).

(*a*) Baroda-Surat-Bombay 264 miles (289 gross) in fore direction along the B. B. and C. I. Railway line. This line forms part of the new net lines 112 and 122.

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[*] The first of these figures represents 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.

[†] i. e., 2 × 116.

[‡] When relevelments are expressed as a percentage, this percentage refers to the amount of back or fore (second direction) levelling only, since it is only on such levelling that relevelments occur. In the case of revision levelling relevelments occur in either or both directions.

(*b*) Portion Khāmgaon to Akola in fore direction 38 miles (42 gross) and Akola-Mhasvād-Dhūlia in the back direction 163 miles (174 gross) partly along roads and partly along the railway line via Bālāpur, Nāndūra Buzruk, Wadner, Malkāpur, Bodvad R. S. and Mhasvād. This line forms part of the new net line 114.

No. 2 detachment under Mr. P. B. Roy did high precision levelling from Sehore to Dhūlia 256 miles in the back direction, following the old route of main-line 34 (Nāndgaon-Sironj) throughout. Total mileage was 256 miles (278 gross) with 116 miles of relevelments (45%). This line forms new net line 111.

No. 3 detachment under Computer P. John did the following high precision levelling, his total out-turn being 78 miles (105 gross) with 4 miles of relevelments (18%).

(*a*) Branch-lines Mhasvād-Pāchora and Mhasvād-Shirsoli in back direction, along the G. I. P. Railway lines, 22 miles. This forms part of new net line 114.

(*b*) Mhasvād-Khāmgaon in fore direction, partly along the road and partly along the railway line via Malkāpur 78 miles (83 gross). This forms part of new net line 114. On completion of the above lines, Computer P. John fell ill and was replaced by Mr. J. N. Kohli.

No. 4 detachment under Mr.Mohd. Faizul Hasan with Computer Sami Ullah Khan as second leveller was first employed on secondary levelling as follows:—

(*a*) Along detached sections of the railway falling in the Asansol Division for the East Indian Railway. Total mileage 162 miles (171 gross).

(*b*) Tīnpahār-Pīrpainti-Purnea was run for departmental purposes in order to detect the 2-foot error revealed last field season, while carrying out levelling from Khāna to Kiul for the East Indian Railway. Total mileage 78 miles (83 gross). It ran along the railway line up to Pīrpainti and thence along the road and across country to Purnea, crossing the Ganges and the Kosi *en route* by target method, as modified by Captain G. Bomford. The results of this levelling are discussed in Geodetic Report Vol. VI, pages 104 to 106.

Owing to financial stringency the railway were compelled to stop the construction of bench-marks on the remaining sections. This detachment was broken up and formed into a high precision one, and the following high precision levelling was carried out:—

(1) Jhānsi-Bīna in the back direction, partly along the road and partly along the railway line via Lalitpur 101 miles (109 gross). This forms part of new net line 109.

(2) Gwalior-Jhānsi in the back direction along the main road via Datia, 64 miles (79 gross). This forms new net line 109A. In addition to the above, 20* miles of check-levelling was done in Bīkaner in both directions in connection with the proposed new Standard Bench Mark.

No. 5 detachment under Mr. I. D. Suri with Computer Hamid Ullah Khan as second leveller, was employed on the following secondary levelling in connection with the Bhakra Dam Project Area (Punjab Irrigation) :—

(*a*) Ferozepore-Jagraon, partly along the railway line (Ferozepore-Jullundur section) and partly along the unmetalled road via Jogwāla R. S. and Dharmkot. Total mileage 76 miles (89 gross).

(*b*) Mahna-head of the Bhadaur distributary, along the Harike-Sāhna road via Badhni Kalān. Total mileage 29 miles (31 gross).

(*c*) Badhni Kalān-Alamwāla, along Abohar Branch (Sirhind Canal) via Samālsar and Asa Buttar. Total mileage 63 miles (82 gross).

(*d*) Bhatinda-Dorāha, along the Bhatinda Branch (Sirhind Canal) via the head of the Bhadaur distributary. Total mileage 84 miles (99 gross).

(*e*) Islāmwāla-Lambi, partly along the Bīkaner main canal and Lambi distributary and partly across country via Dānewāla, Dewān Khera and Waryām Khera. Total mileage 75 miles (92 gross).

(*f*) Hanumāngarh-Hissār, partly along the southern and northern Ghaggar (Inundation) canals and partly across country via Sirsa, Bhādra and Bālsamand. Total mileage 132 miles (150 gross).

(*g*) Hissār-Bālsamand, partly along the road and railway line and partly across country via Hānsi, Bhiwāni, Roda and Siwāni. Total mileage 100 miles (114 gross).

No. 6 detachment under Mr. A. A. S. Matlub Ahmad with Computer Yasub Hasan as second leveller, was employed on the following secondary levelling in connection with the Bihār and Orissa Flood Area (Irrigation).

(*a*) Muhammadnagar Patna-Bhadrakh, partly along the Orissa coast canal and the Chāndbāli-Bhadrakh road and partly across country via Bāthagān, Balasore, Bideipur and Pīr Hāt. Total mileage 152 miles (156 gross).

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* i. e., 2 × 10.

(*b*) Bhadrakh-Cuttack, partly along the Orissa Trunk road and railway line and partly along the high level canal via Jenāpur and Choudwār. Total mileage 91 miles (102 gross).

(*c*) Cuttack-Pīr Hāt, along the Orissa Trunk road for a short distance and mainly across country via Achyutpur, Kendrāpāra and Chāndbāli. Total mileage 149 miles (149 gross).

No. 7 detachment under Mr. B. P. Rundev with Computer I. M. Saklani as second leveller, was employed on the following levelling:—

(*a*) Mandalay-Sagaing, secondary, along the railway line via Amarapura Shore, crossing the Irrawaddy *en route* by target method, as modified by Captain G. Bomford, making use of an island, the width being about 66 chains. Total mileage 17 miles (19 gross). This work was carried out for the Burma Railway in connection with the Irrawaddy bridge between Sagaing and Amarapura.

(*b*) Taunggyi-Kengtung, precise, partly along the motor road and partly along the bridle-path via Loi Lem and Takaw, crossing the Nampang and the Salween rivers *en route* by direct levelling. This line was carried out to correct trigonometrical heights of the Mong Hsat series, and eventually to effect a connection with the high precision levelling of Siam. Total mileage 261 miles (276 gross).

Tertiary levelling.—Owing to large discrepancies having been noticed between the Survey and P. W. D. levelling, this party had to undertake the revision of the E. to W. lines of single tertiary levelling in 64 sheets, amounting to 6,400 linear miles in the Bahāwalpur State, of which about 600 miles were *partalled* and revised this field season, under Computer Syed Nayar Hasan, the remaining portion will be carried out during 1931-32.

4. **Probable Errors.**—Probable errors of the high precision lines have been computed by the formulæ:—

$$\sigma_r = \frac{S}{3L}; \quad \eta_r = \sqrt{\left[\frac{\Sigma\Delta^2}{9L} - \sigma_r^2 \times \frac{\Sigma r^2}{L}\right]}$$

where σ_r = probable systematic error.

η_r = probable accidental error.

Δ = discordance of the results of the fore and back levelling between consecutive bench-marks.

S = total discordance.

r = distance between consecutive bench-marks.

L = total distance.

These are given below in foot and mile units:—

Line	Probable accidental error	Probable systematic error
111 Sehore-Dhūlia	± 0·00370	± 0·00040
109 Jhānsi-Bīna	± 0·00320	± 0·00016
109A Gwalior-Jhānsi	± 0·00285	± 0·00004
114 Dhūlia-Akola	± 0·00287	± 0·00036

Permissible probable accidental and systematic errors are ±0·00416 and ±0·00106 feet respectively.

Probable errors of secondary levelling were computed by 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. 4 Dett.	74 M Tīnpahār-Pīrpainti	±0·00369
”	74 P Pīrpainti-Purnea	±0·00422
”	70 U Pradhānkhunta-Pāthardīh	±0·00395
”	70 V Dhānbād-Jamuniātānr	±0·00449
”	70 S Mānpur-Luckeesarai	±0·00476
”	70 T Patna-Gaya	±0·00469
No. 5 Dett.	56 I Ferozepore-Jagraon	±0·00401
”	61 I Mahna-head of Bhadaur distributary	±0·00426
”	61 J Badhni Kalān-Alamwāla	±0·00369
”	57 O Bhatinda-Dorāha	±0·00351
”	57 P Islāmwāla-Lambi	±0·00374
”	57 Q Hanumāngarh-Hissār	±0·00417
”	57 R Hissār-Bālsamand	±0·00488
No. 6 Dett.	75 B Muhammadnagar Patna-Bhadrakh	±0·00292
’	75 C Bhadrakh-Cuttack	±0·00402
”	75 D Cuttack-Pīr Hāt	±0·00372
No. 7 Dett.	89 Mandalay-Sagaing	±0·00312
”	88 K Taunggyi-Me-Sai Bridge (Siamese Border), portion Taunggyi-Kengtung	±0·00500

5. Progress of the new level net.—The following additions were made to the completed mileage of the new level net:—

Line No.	Name of Line	Miles completed on main-line	REMARKS
111	Sehore-Dhūlia ...	256	The whole line is complete.
109	Jhānsi-Bīna ...	101	Do.
109A	Gwalior-Jhānsi ...	64	Do.
114	Dhūlia-Nāgpur ...	163	Portion Akola-Nāgpur not completed yet.
	Total ...	584	
	Previously completed	8,199*	
	Total completed to date	8,783	

In addition to the above, 264 miles have been completed in one direction only which is equivalent to 132 miles in both directions making an equivalent total of 8,915 miles. The total mileage of the new level net is now about 15,800 miles.

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* Disagrees with previous year's report on account of exclusion of line No. 101A (Sukkur-Hyderābād) which has since been treated as secondary.

TABLE 1.—*Tabular statement of out-turn of work, season 1930-31.*

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		
		Main-line	Extras and branch-lines	Total	Rises	Falls		Primary		Secondary
								Rock-cut Protected	Other Primary	
		Mls.	Mls.	Mls.	feet	feet				
No. 1 Detachment.										
Part of line 112 Baroda-Surat (fore)	Oct. 30 to Nov. 30	95	11	106	826	812	1.182	...	10	123
Part of line 122 Surat-Bombay (fore)	Nov. 30 to Dec. 30 & Mar. 31 to April 31	169	14	183	1,883	1.444	1.990	...	4	205
Part of line 114 Khāmgaon-Akola (fore)	Dec. 30	38	4	42	960	836	522	...	2	41
Part of line 114 Dhūlia-Akola (1) (back)	Dec. 30 to Mar. 31	163	11	174	3.433	4.050	2,144	...	5	183
No. 2 Detachment.										
Line 111 Sehore-Dhūlia (2) (back)	Oct. 30 to April 31	256	22	278	6,707	5,995	3.770	...	4	345
No. 3 Detachment.										
Parts of line 114 (*a*) Mhasvād-Khāmgaon (fore)	Oct. 30 to Nov. 30	78	5	83	2.348	1,821	1.178	..	2	84
(*b*) Branch-lines at Mhasvād (3) (back)	Oct. 30	...	22	22	265	100	254	...	...	6
No. 4 Detachment.										
Part of line 109 Jhānsi-Bīna (4) (back)	Jan. 31 to Feb. 31	101	8	109	1.622	2.132	1.464	...	2	133
Line 109A Gwalior-Jhānsi (5) (back)	Mar. 31 to April 31	64	15	79	1.239	1,689	1,100	...	3	97
Check-levelling & branch-line at Bikaner (fore)	April 31	...	10	10	57	114	126	.	1	5 & 10*

*Temporary marks. *(Continued).*

(1) Relevelled 51 miles. (2) Relevelled 116 miles. (3) Relevelled 4 miles.
(4) „ 15 „ (5) „ 10 „ .

TABLE 1.—*Tabular statement of out-turn of work, season 1930-31—(contd.).*

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		
		Main-line	Extras and branch-lines	Total	Rises	Falls		Primary		Secondary
								Rock-cut Protected	Other Primary	
		Mls.	Mls.	Mls.	feet	feet				
No. 4 Detachment.										
(*Concld.*).										
Check-levelling & branch-line at Bikaner (back)	April 31	...	10	10	117	61	136	...	1	5 & 10*
Part of branch-line 74M Tīnpahār-Pīrpainti (revision)	Oct. 30	38	1	39	299	268	430	...	...	25
Branch-line 74P Pīrpainti-Purnea	Oct. 30 to Nov. 30	40	4	44	362	397	500	...	1	49
Branch-line 70S Mānpur-Luckeesarai	Nov. 30 to Dec. 30	76	4	80	352	549	884	...	...	71
Branch-line 70T Patna-Gaya	Dec. 30	59	...	59	389	200	642	...	1	54
Branch-line 70U Pradhānkhunta-Pāthardih	Nov. 30	10	2	12	157	272	152	...	...	17
Branch-line 70V Dhānbād-Jamuniātānr	Nov. 30	17	3	20	308	498	280	...	...	26
No. 5 Detachment.										
Branch-line 56I Ferozepore-Jagraon	Oct. 30	76	13	89	597	496	858	...	3	98
Branch-line 61I Mahna-head of Bhadaur distributary	Nov. 30	29	2	31	275	251	338	...	...	51
Branch-line 61J Badhni Kalān-Alamwāla	Nov. 30 to Dec. 30	63	19	82	469	603	818	...	2	125

* Temporary marks.

(Continued).

TABLE 1.—*Tabular statement of out-turn of work, season 1930-31—(concld.).*

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		
		Main-line	Extras and branch-lines	Total	Rises	Falls		Primary		Secondary
								Rock-cut Protected	Other Primary	
		Mls.	Mls.	Mls.	feet	feet				
No. 5 Detachment. *(Concld.).*										
Branch-line 57O Bhatinda-Dorāha	Dec. 30 to Jan. 31	84	15	99	677	501	904	...	1	139
Branch-line 57P Islāmwāla-Lambi	Jan. 31	75	17	92	467	438	822	...	...	104
Branch-line 57Q Hanumāngarh-Hissār	Feb. 31 to Mar. 31	132	18	150	1,093	1,010	1,370	...	3	120
Branch-line 57R Hissār-Bālsa-mand	Mar. 31 to May 31	100	14	114	1,369	1,386	1,208	...	2	89
No. 6 Detachment.										
Branch-line 75B Muhammad-nagar Patna-Bhadrakh	Jan. 31 to Mar. 31	152	4	156	1,126	1,121	1,730	...	2	81
Branch-line 75C Bhadrakh-Cuttack	Oct. 30 to Nov. 30	91	11	102	726	689	1,018	...	2	80
Branch-line 75D Cuttack-Pīr Hāt	Nov. 30 to Jan. 31	149	...	149	1,092	1,166	1,524	...	2	80
No. 7 Detachment.										
Part of branch-line 88K Taunggyi-Me-Sai Bridge (Siamese Border), portion Taunggyi-Kengtung	Nov. 30 to April 31	261	15	276	29,488	28,680	8,984	...	10	247
Part of line 89 Mandalay-Sagaing	Oct. 30	17	2	19	343	334	296	...	3	22

TABLE 2.—*Check-levelling.*

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

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by			Difference (check-original). The sign + denotes that the height was greater and the sign − less in 1930-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1930-31	
			miles		*feet*	*feet*	*feet*
			At Baroda on line 112.				
48	46 F	Standard (Type P)...	0·00	1909-10	0·000	0·000	0·000
*	,,	Plinth of *kothi* ...	0·03	1928-30	+ 1·049	+ 1·045	− 0·004
117	,,	Plinth of office ..	0·09	1909	+ 1·302	+ 1·293	0·009
*	,,	Flooring of office ...	0·19	1928-30	+ 1·340	+ 1·337	− 0·003
119	,,	State library ...	0·30	1909	+ 1·847	+ 1·837	− 0·010
120	,,	Step of office ...	0·36	,,	+ 2·390	+ 2·381	− 0·009
*	,,	Flooring of office ...	0·43	1928-30	+ 3·384	+ 3·383	− 0·001
116	,,	Plinth of portico ...	0·86	1909	− 18·958	− 18·961	− 0·003
17	,,	Temple	0·96	,,	− 21·517	− 21·542	− 0·025
114	,,	Stone sill	1·31	,,	− 14·906	− 14·915	− 0·009
113	,,	Step of museum	1·73	,,	− 17·673	− 17·679	− 0·006
112	,,	Step of church ...	2·33	,,	− 18·931	− 18·920	+ 0·011
14	,,	Embedded B.M. ..	2·70	,,	− 18·122	− 18·136	− 0·014
			At Surat on lines 112 and 122.				
70	46 C	Standard (Type P)	0·00	1909-10	0·000	0·000	0·000
71 (*69*)	,,	Step of school ..	0·14	1921-22 & 26-27	− 8·831	− 8·839	− 0·008
68	,,	Paving at institute	0·20	1875-78	− 3·665	− 3·679	− 0·014
67	,,	Paving at hospital .	0·49	,,	− 2·236	− 2·245	− 0·009
72 (*66*)	,,	Plinth at reservoir	0·65	1921-22 & 26-27	+ 2·508	+ 2·502	− 0·006
73 (*46*)	,,	Step at clock tower...	1·10	,,	− 3·098	− 3·091	+ 0·007
65	,,	Paving at dispensary	1·13	1875-78	− 1·339	− 1·337	+ 0·002
74 (*45*)	,,	Step at *dharmshāla*	1·81	1921-22 & 26-27	− 1·563	− 1·498	+ 0·065
75 (*63*)	,,	Coping of platform ..	1·98	,,	+ 15·471	+ 15·512	+ 0·041
76 (*64*)	,,	Embedded B.M.	1·99	,,	+ 13·977	+ 13·948	− 0·029
			At Bombay† on line 122.				
1 (2)	47 B	Standard (Type P)...	0·00	1906-07	0·000	0·000	0·000
88 (5)	,,	Step at university ...	0·26	,,	− 3·540	− 3·525	+ 0·015
87 (6)	,,	Step at university ...	0·26	,,	− 3·458	− 3·444	+ 0·014
84	,,	Step of fountain	0·68	1914-15	+ 2·584	+ 2·588	+ 0·004
129	,,	Newel at Apollo pier	0·90	,,	− 2·977	− 2·958	+ 0·019
130 (9)	,,	Flooring at Apollo *bandar*	0·95	1906-07	− 6·035	− 6·020	+ 0·015
85	,,	Stone at band-stand	1·51	1914-15	− 7·171	− 7·161	+ 0·010
89	,,	Step at Colāba R.S.	2·25	,,	− 5·624	− 5·618	+ 0·006

(Continued).

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* Topo. Nos. of these bench-marks are not available, as portion Viramgām-Baroda has not yet been adjusted.

† Bracketed Topo. Nos. in the check-levelling at Bombay are usual Topo. Nos. and the others refer to Bombay Island levelling.

TABLE 2.—*Check-levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1930-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1930-31	
			miles		*feet*	*feet*	*feet*
At Bombay on line 122.—(concld.).*							
90	47 B	Plinth at church	2·70	1914-15	− 3·352	− 3·338	+ 0·014
91	„	Step at church	3·12	„	− 0·008	+ 0·001	+ 0·009
92	„	Step at barrack No. 5	3·53	„	+ 5·893	+ 5·898	+ 0·005
93 (23)	„	Bed-rock ...	3·80	1906-07	+ 13·816	+ 13·827	+ 0·011
94	„	Embedded B.M. .	3·82	1914-15	+ 12·205	+ 12·214	+ 0·009
95 (8)	„	Colāba G.T. Station	3·86	1906-07	+ 14·138	+ 14·176	+ 0·038
2 (4)	„	Step at G.T.O. ...	0·05	„	− 2·139	− 2·132	+ 0·007
3 (3)	„	Step at G.T.O. ...	0·05	„	− 2·173	− 2·172	+ 0·001
4	„	Plinth of offices ...	0·23	1914-15	− 4·711	− 4·698	+ 0·013
6	„	Step of house ...	0·41	„	− 5·912	− 5·902	+ 0·010
7	„	Plinth of bungalow	0·67	„	− 2·427	− 2·411	+ 0·016
8	„	Plinth of bungalow	1·12	„	− 3·161	− 3·255	− 0·094
10	„	Embedded B. M. ...	1·50	„	− 5·497	− 5·499	− 0·002
9	„	Step of cemetry ...	1·54	„	− 4·488	− 4·488	0·000
11	„	Plinth of institute ...	1·78	„	− 3·403	− 3·406	− 0·003
12	„	Plinth of building ...	1·98	„	− 4·490	− 4·529	− 0·039
At Dhūlia on line 114.							
107	46 L	Standard (Type P) ..	0·00	1909-10	0·000	0·000	0·000
147 (*106*)	„	Flooring of school .	0·25	1921-22 & 26-27	− 5·489	− 5·498	− 0·009
148 (*108*)	„	Step at clock tower	0·53	..	− 2·971	− 2·989	− 0·018
109	„	Veranda of *tahsīl* ...	0·65	1909-10	+ 2·246	+ 2·241	− 0·005
110	„	Flooring of school ..	0·82	„	+ 11·279	+ 11·275	− 0·004
77	„	Bridge	0·97	1877-78 & 83-84	+ 8·628	+ 8·643	+ 0·015
76	„	Milestone ..	1·17	1909-10	+ 12·946	+ 12·949	+ 0·003
111	„	Rock in situ ..	2·01	„	+ 37·563	+ 37·574	+ 0·011
112	„	Rock in situ ..	2·52	„	+ 63·566	+ 63·575	+ 0·009
At Akola on line 114.							
3	55 H	Standard (Type P) ...	0·00	1909-10	0·000	0·000	0·000
4	„	Flooring of court ...	0·87	1877-78 & 90-92	− 26·424	− 26·422	+ 0·002
2	„	Embedded B. M. ...	1·13	„	− 32·830	− 32·835	− 0·005
5	„	Flooring of house ...	0·09	„	+ 0·742	+ 0·729	− 0·013

(*Continued*).

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* Bracketed Topo. Nos. in the check-levelling at Bombay are usual Topo. Nos. and the others refer to Bombay Island levelling.

TABLE 2.—*Check-levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by			Difference (check−original). The sign + denotes that the height was greater and the sign −, less in 1930-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1930-31	
			miles		*feet*	*feet*	*feet*
				At Sehore on line 111.			
151 (2)	55 E	Embedded B.M. ...	0 00	1928-30	0·000	0·000	0·000
152	,,	Step of P. & T. O. ..	0·08	,,	+ 0·047	+ 0·005	−0·042
153	,,	Step to well ...	0·18	,,	− 1·458	− 1·473	−0·015
150	,,	Curb of well ...	0·49	,,	+ 15·728	+ 15·721	−0·007
149	,,	Plinth of *kachahri* ...	0·53	,,	+ 12·777	+ 12·767	−0·010
148	,,	Flooring of hospital	0·60	,,	+ 11 924	+ 11·911	−0·013
147	,,	Curb of well ...	0·84	,,	+ 13·902	+ 13·895	−0·007
154	,,	Tomb	0·36	,,	− 8·783	− 8·784	−0·001
155	,,	Road culvert ...	1·00	,,	+ 15·296	+ 15·292	−0·004
156	,,	Curb of well ...	1·18	,,	+ 21·417	+ 21·450	+0·033
157	,,	Flooring of veranda	1·25	,,	+ 23·043	+ 23·073	+0·030
				At Dhūlia on line 111.			
107	46 L	Standard (Type P)...	0·00	1909-10	0·000	0·000	0·000
147 (106)	,,	Flooring of school ...	0·26	1926-27	− 5·489	− 5·515	− 0·026
148 (108)	,,	Step of clock tower...	0·56	,,	− 2 971	− 3·003	− 0·032
109	,,	Paving of veranda	0·69	,,	+ 2·246	+ 2·224	− 0·022
110	,,	Plinth of school ...	0·88	,,	+ 11·279	+ 11·261	− 0·018
77	,,	Bridge	1·04	,,	+ 8·628	+ 8·621	− 0·007
76	,,	Milestone ...	1·24	,,	+ 12·946	+ 12·936	− 0·010
111	,,	Rock in situ ...	2·09	,,	+ 37·563	+ 37·565	+ 0 002
149 (75)	,,	Bridge	2 11	..	+ 42·079	+ 42·067	− 0·012
112	,,	Rock in situ ...	2·60	,,	+ 63·566	+ 63·569	+ 0·003
				At Jhānsi on line 109.			
51	54 K	Standard (Type P)...	0·00	1906-07	0·000	0·000	0·000
50	,,	Stone step ...	0·03	,,	− 0·798	− 0·800	− 0·002
49	,,	Stone step ..	0·07	,,	− 0·747	− 0·757	− 0·010
111	,,	Rock	0·86	1917-18	− 12·000	− 12·000	0·000
110	,,	Stone flooring ...	1·36	,,	− 42·993	− 42·996	− 0·003
109	,,	Rock ...	1·69	,,	− 39·409	− 39·434	− 0·025
108	,,	Stone flooring ...	1·75	,,	− 31·754	− 31·769	− 0·015
47	,,	Stone flooring ...	1·00	1906-07	+ 23 353	+ 23·355	+ 0·002
43	,,	Ry. platform ...	1·58	,,	+ 2·405	+ 2·464	+ 0·059
44	,,	Ry. platform ...	1·69	,,	+ 2·369	+ 2·361	− 0·008
48	,,	Stone flooring ...	2·16	,,	+ 8·548	+ 8·557	+ 0·009

(*Continued*).

TABLE 2.—*Check-levelling*—(*concld.*).

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

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1930-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1930-31	
			miles		*feet*	*feet*	*feet*
At Bīna on line 109.							
18	54 L	Embedded B.M. ...	0·00	1898-99	0·000	0·000	0·000
16	,,	Bridge	2·18	,,	+ 53·503	+ 53·509	+ 0·006
15	,,	Bridge	2·78	,,	+ 40·173	+ 40·156	− 0·017
14	,,	Bridge	3·71	,,	+ 29·217	+ 29·182	− 0·035
At Gwalior on line 109A.							
31	54 J	Standard (Type P) ...	0·00	1905-06	0·000	0·000	0·000
59	,,	Stone step ...	0·55	1915-16	− 7·469	− 7·474	− 0·005
58	,,	Well	1·89	,,	− 17·505	− 17·514	− 0·009
28	,,	Culvert	2·25	,,	− 31·047	− 31·058	− 0·011
57	,,	Stone flooring ...	2·93	,,	− 37·003	− 37·009	− 0·006
At Jhānsi on line 109A.							
51	54 K	Standard (Type P) ...	0·00	1906-07	0·000	0·000	0·000
111	,,	Bed-rock	0·75	1917-18	− 12·000	−- 11·993	+ 0·007
110	,,	Stone flooring	1·24	,,	− 42·993	− 42·991	+ 0·002
109	,,	Rock	1·57	,,	− 39·409	− 39·429	− 0·020
108	,,	Stone flooring ...	1·63	,,	− 31·754	− 31·751	+ 0·003
107	,,	Rock	1·87	,,	− 40·840	− 40·844	− 0·004
106	,,	Rock	2·46	,,	− 37·127	− 37·120	+ 0·007
At Bīkaner on line 57A.							
1	45 E	Standard (Type P) ..	0·00	1907-08	0·000	0·000	0·000
2	,,	Masonry block ...	0·21	1907-09	− 6·967	− 6·966	+ 0·001
52	44 H	Plinth	0·68	,,	− 3·494	− 3·517	− 0·023
49	,,	Masonry block ...	4·62	,,	− 10·077	− 10·080	− 0·003
48	,,	Masonry block ..	6·59	,,	− 5·950	− 5·964	− 0·014
47	,,	Masonry block ...	8·56	,,	− 43·057	− 43·073	− 0·016
At Taunggyi on line 88K.							
1	93 H	Standard (Type P) ...	0·00	1913-14	0·000	0·000	0·000
104	93 D	Rock ...	2·84	,,	−1,126·731	−1,126·766	− 0·035
2	93 H	Rock	0·82	,,	+ 123·505	+ 123·515	+ 0·010

TABLE 3.—*Revision levelling.*

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision−original). The sign + denotes that the height was greater and the sign −, less in 1929-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1929-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(Dhūlia to Akola) old lines 34 and 35, new 114.					
107	46 L	S.B.M. at Dhūlia ...	0·00	1909-10	0·000	0·000	0·000
147 (*106*)	,,	School	0·25	1921-22 & 26-27	− 5·489	− 5·501	− 0·012
148 (*108*)	,,	Step of clock tower . .	0·53	,,	− 2·971	− 2·991	− 0·020
109	,,	Veranda of *tahsīl* ...	0·65	1909-10	+ 2·246	+ 2·238	− 0·008
110	,,	Flooring of school ..	0·82	,,	+ 11·279	+ 11·271	− 0·008
77	,,	Bridge	0·97	1877-78 & 83-84	+ 8·628	+ 8·637	+ 0·009
76	,,	Top of milestone ...	1·17	1909-10	+ 12·946	+ 12·946	0·000
111	,,	Rock	2·01	,,	+ 37·563	+ 37·576	+ 0·013
112	,,	Rock	2·52	,,	+ 63·566	+ 63·578	+ 0·012
45	46 P	Bridge	50·01	1877-78 & 90-92	− 174·439	− 174·480	− 0·041
49	,,	Well	53·29	,,	− 164·300	− 164·288	+ 0·012
40	,,	Embedded at Māheji R.S.	54·48	,,	− 61·591	− 61·832	− 0·241
38	,,	Bridge	58·15	,,	− 57·973	− 58·220	− 0·247
34	,,	Embedded at Pāchora R.S.	63·57	,,	− 0·631	− 0·921	− 0·290
3	55 D	Coping of platform ...	88·21	,,	+ 103·549	+ 103·545	− 0·004
4	,,	Embedded at Bodvad R.S.	88·22	,,	+ 103·267	+ 103·247	− 0·020
9	,,	Culvert	93·37	,,	+ 15·980	+ 16·032	+ 0·052
10	,,	Culvert	94·78	,,	− 24·156	− 22·751	+ 1·405
14	,,	Culvert	97·57	,,	− 36·649	− 36·521	+ 0·128
15	,,	Culvert ...	98·85	,,	− 26·813	− 25·017	+ 1·796
17	,,	Embedded at Malkāpur R.S.	100·49	,,	− 38·933	− 38·936	− 0·003
38	,,	Coping of platform ..	119·16	,,	+ 11·028	+ 11·104	+ 0·076
39	,,	Embedded at Nāndūra R.S.	119·17	,,	+ 10·672	+ 10·772	+ 0·100
5	55 H	Flooring ...	162·50	,,	+ 96·498	+ 96·506	+ 0·008
3	,,	S.B.M. at Akola ...	162·59	1908-09	+ 95·756	+ 95·777	+ 0·021
4	,,	Flooring ...	163·46	1877-78 & 90-92	+ 69·332	+ 69·355	+ 0·023
2	,,	Embedded at Akola R.S.	163·72	,,	+ 62·926	+ 62·940	+ 0·014

(Continued).

TABLE 3.—*Revision levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision − original). The sign + denotes that the height was greater and the sign −, less in 1929-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1929-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
(*Sehore to Dhūlia*) *old line 34, new 111.*							
151 (2)	55 E	Embedded at Sehore	0·00	1877-78 & 83-84	0·000	0·000	0·000
156 (*6*)	55 A	Embedded at Amlai	12·95	,,	− 4·660	− 4·910	− 0·250
157 (*5*)	,,	*Satī* tomb ...	12·98	,,	− 7·151	− 6·960	+ 0·191
166 (*2*)	,,	Embedded at Ashta	26·16	,,	− 10·332	− 10·722	− 0·390
35 (*26*)	55 B	Shrine	45·55	,,	+ 41·052	+ 39·701	− 1·351
39 (*25*)	,,	Mile	47·65	,,	− 0·983	− 1·415	− 0·432
24	,,	Embedded at Daulatpur	48·56	,,	− 2·841	− 2·877	− 0·036
41 (*23*)	,,	Culvert	49·33	,,	− 18·276	− 18·284	− 0·008
43 (*22*)	,,	Mile ...	50·70	,,	− 32·515	− 35·178	− 2·663
45 (*21*)	,,	Bridge ...	51·26	,,	− 62·529	− 62·765	− 0·236
48 (*20*)	,,	Mile	52·75	,,	− 59·415	− 61·686	− 2·271
50 (*19*)	,,	Bridge ...	53·79	,,	− 67·299	− 67·315	− 0·016
52 (*18*)	,,	Culvert	55·35	,,	− 25·088	− 25·084	+ 0·004
17	,,	Bridge ...	56·99	,,	− 46·488	− 46·537	− 0·049
59 (*14*)	,,	Mile ...	61·88	,,	− 13·730	− 13·144	+ 0·586
60 (*13*)	,,	Culvert ...	62·43	,,	− 0·729	− 0·695	+ 0·034
63 (*12*)	,,	Culvert ...	64·75	,,	+ 57·899	+ 57·926	+ 0·027
64 (*11*)	,,	Culvert	65·26	,,	+ 66·428	+ 66·464	+ 0·036
66 (*10*)	,,	Culvert	66·79	,,	+ 110·508	+ 110·552	+ 0·044
67 (*9*)	,,	Culvert	67·84	,,	+ 120·452	+ 120·486	+ 0·034
68 (*8*)	,,	Culvert	68·68	,,	+ 154·161	+ 153·695	− 0·466
71 (*6*)	,,	Bridge ...	71·53	,,	+ 168·060	+ 168·003	− 0·057
72 (*5*)	,,	Embedded at Dewās	71·81	,,	+ 171·721	+ 171·771	+ 0·050
73 (*4*)	,,	Step to quarters ...	73·01	,,	+ 139·991	+ 140·013	+ 0·022
75 (*3*)	,,	Mile	74·39	,,	+ 110·400	+ 109·011	− 1·389
76 (*2*)	,,	Mile	75·39	,,	+ 125·521	+ 125·290	− 0·231
89 (*82*)	46 N	Mile	78·40	,,	+ 84·517	+ 84·104	− 0·413
81	,,	Temple	79·25	,,	+ 48·671	+ 48·562	− 0·109
90 (*80*)	,,	Mile ...	80·45	,,	+ 76·570	+ 76·296	− 0·274
91 (*79*)	,,	Bridge ...	81·25	,,	+ 85·518	+ 84·685	− 0·833
93 (*76*)	,,	Mile ...	83·45	,,	+ 109·997	+ 109·727	− 0·270
95 (*75*)	,,	Mile	85·45	,,	+ 157·490	+ 157·509	+ 0·019
74	,,	Mile	86·45	,,	+ 131·029	+ 130·907	− 0·122
73	,,	Bridge	87·85	,,	+ 145·735	+ 145·612	− 0·123
98 (*72*)	,,	Mile ...	88·45	,,	+ 156·137	+ 155·318	− 0·819
101 (*71*)	,,	Mile	90·44	,,	+ 185·958	+ 185·840	− 0·118
105 (*69*)	,,	Mile	93·23	,,	+ 190·856	+ 190·507	− 0·349
109 (*68*)	,,	Embedded at Indore	94·40	,,	+ 189·017	+ 188·758	− 0·259
111 (*66*)	,,	Bridge	94·84	,,	+ 189·051	+ 188·914	− 0·137
113 (*65*)	,,	Bridge	96·11	,,	+ 196·696	+ 196·553	− 0·143

(*Continued*).

TABLE 3.—*Revision levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision−original). The sign + denotes that the height was greater and the sign −, less in 1929-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1929-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(*Sehore to Dhūlia*) *old line 34, new 111.*—(*contd.*).					
115 (*63*)	46 N	Bridge	97·85	1877-78 & 83-84	+ 227·277	+ 227·150	− 0·127
117 (*62*)	,,	Bridge	99·69	,,	+ 252·596	+ 252·490	− 0·106
119 (*61*)	,,	Gate-lodge ...	101·33	,,	+ 288·295	+ 288·173	− 0·122
120 (*60*)	,,	Platform ...	101·78	,,	+ 299·674	+ 299·512	− 0·162
59	,,	Railway bridge ...	103·19	,,	+ 280·872	+ 280·696	− 0·176
124 (57)	,,	Railway bridge ...	105·74	1909-10	+ 240·409	+ 240·554	+ 0·145
56	,,	Railway bridge ...	106·33	1877-78 & 83-84	+ 240·715	+ 240·520	− 0·195
125 (52)	,,	Railway bridge ...	106·84	1909-10	+ 245·095	+ 245·368	+ 0·273
54	,,	Embedded at Mhow	107·81	,,	+ 270·538	+ 270·332	− 0·206
126 (*88*)	,,	Temple ...	108·00	,,	+ 272·857	+ 272·616	− 0·241
127 (*87*)	,,	Stone	108·51	,,	+ 270·522	+ 270·274	− 0·248
86	,,	Church ...	109·24	,,	+ 317·340	+ 317·129	− 0·211
128 (*85*)	,,	Bridge ...	109·56	,,	+ 291·456	+ 291·214	− 0·242
83	,,	S B. M at Mhow ...	110·31	,,	+ 313·603	+ 313·387	− 0·216
130 (*49*)	,,	Mile	111·23	1877-78 & 83-84	+ 298·080	+ 297·252	− 0·828
131 (*48*)	,,	Mile	112·23	,,	+ 371·538	+ 371·291	− 0·247
132 (*47*)	,,	Mile	113·23	,,	+ 365·514	+ 365·591	+ 0·077
133 (*46*)	,,	Mile	114·25	,,	+ 406·902	+ 406·721	− 0·181
136 (*44*)	,,	Mile	116·30	,,	+ 441·841	+ 441·660	− 0·181
140 (*42*)	,,	Mile	120·34	,,	+ 296·936	+ 296·475	− 0·461
143 (*40*)	,,	Singārchori H S	125·05	,,	+ 1274·406	+ 1273·156	− 1·250
144 (*41*)	,,	Mile	121·35	,,	+ 329·836	+ 329·621	− 0·215
149 (*38*)	,,	Embedded at Mānpur	124·51	,,	+ 226·428	+ 226·266	− 0·162
151 (*37*)	,,	Mile	125·58	,,	+ 198·734	+ 198·522	− 0·212
154 (*35*)	,,	Mile	127·58	,,	− 59·897	− 60·444	− 0·547
155 (*34*)	,,	Bridge ...	128·14	,,	− 170·964	− 171·106	− 0·142
156 (*33*)	,,	Mile ...	128·49	,,	− 126·698	− 127·633	− 0·935
32	,,	Mile	129·50	,,	− 167·501	− 167·756	− 0·255
157 (*31*)	,,	Mile	130·51	,,	− 172·949	− 173.395	− 0·446
30	,,	Bridge	133·08	,,	− 652·331	− 652.572	− 0·241
162 (*29*)	,,	Mile	134·55	,,	− 731·842	− 732.126	− 0·284
163 (*28*)	,,	Mile	135·55	,,	− 806·833	− 807.566	− 0·733
27	,,	Mile	136·55	,,	− 852·437	− 852.695	− 0·258
26	,,	Embedded at Gujri	137·13	,,	− 856·596	− 856·861	− 0·265
172 (*22*)	,,	Mile	142·61	,,	−1007·568	−1008·585	− 1·017
173 (*21*)	,,	Mile	143·61	,,	−1029·152	−1029·724	− 0·572
176 (*19*)	,,	Mile	145·65	,,	−1064·887	−1065.317	− 0·430
179 (*18*)	,,	Mile	147·69	,,	−1087·988	−1088·236	− 0·248
180 (*17*)	,,	Mile	148·69	,,	−1090·899	−1091·385	− 0·486
16	,,	Embedded at Khalghāt	149·65	,,	−1119·887	−1120,197	− 0·310

(*Continued*).

TABLE 3.—*Revision levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision − original). The sign + denotes that the height was greater and the sign −, less in 1929-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1929-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(Sehore to Dhūlia) old line 34, new 111.—(contd.).					
183 (*15*)	46 N	Bridge	150·50	1877-78 & 83-84	−1098·343	−1098 617	− 0·274
187 (*13*)	,,	Mile	153·58	,,	−1048·008	−1047·087	+ 0·921
189 (*11*)	,,	Mile ...	155·55	,,	−1048·958	−1048·772	+ 0·186
191 (*9*)	,,	Mile	156·49	,,	−1049·876	−1050·170	− 0·294
6	,,	Mile ...	159·50	,,	−1021·713	−1022·034	− 0·321
196 (*5*)	,,	Mile	160·50	,,	−1008·311	−1008·483	− 0·172
4	,,	Well	161·19	,,	− 988·968	− 989·293	− 0·325
197 (*10*)	,,	Thikri H.S.	166·48	,,	− 762·002	− 765·762	− 3·760
198 (*3*)	,,	Embedded at Khurampur ...	161·43	,,	− 940·004	− 940·224	− 0·220
2	,,	Mile	161·66	,,	− 984·200	− 984·531	− 0·331
199 (*1*)	,,	Culvert ...	162·34	,,	− 956·828	− 957·181	− 0·353
64 (*38*)	46 O	Mile	165 65	,,	− 896·252	− 896·500	− 0·248
74 (*31*)	,,	Bridge	173 20	,,	− 835·020	− 836·057	− 1·037
30	,,	Bridge	174·18	,,	− 814·309	− 814·663	− 0·354
29	,,	Embedded at Julwana ...	175·91	,,	− 738·358	− 738·706	− 0·348
28	,,	Mile	176·89	,,	− 772·773	− 773·122	− 0·349
79 (*27*)	,,	Mile	177·89	,,	− 733·977	− 734·284	− 0·307
82 (*26*)	,,	Mile	179·89	,,	− 617·734	− 617·857	− 0 123
84 (*24*)	,,	Mile	181·93	,,	− 582 898	− 582·927	− 0·029
23	,,	Culvert ...	182·93	,,	− 592·791	− 593·143	− 0·352
87 (*22*)	,,	Mile	183 90	,,	− 534 175	− 534·230	− 0·055
21	,,	Mile	184·90	,,	− 500·023	− 500·341	− 0·318
88 (*20*)	,,	Mile	185 90	,,	− 452·309	− 452·604	− 0·295
90 (*19*)	,,	Mile	186·90	,,	− 405·010	− 404·974	+ 0·036
91 (*18*)	,,	Mile	187 90	,,	− 356 562	− 356.868	− 0·306
94 (*17*)	,,	Mile	189 89	,,	− 326 149	− 325 975	+ 0·174
96 (*16*)	,,	Embedded at Sendhwa ...	191 14	,,	− 289·264	− 289 543	− 0·279
98 (*15*)	,,	Culvert ...	192 30	,,	− 241·726	− 242 001	− 0·275
100 (*14*)	,,	Mile	194·06	,,	− 134·490	− 134·762	− 0·272
101 (*13*)	,,	Culvert ...	194·60	,,	− 83 109	− 83·354	− 0·245
103 (*12*)	,,	Culvert ...	196 08	,,	− 4·769	− 5·004	− 0·235
104 (*11*)	,,	Mile	197·03	,,	+ 53·643	+ 53·350	− 0 293
109 (*9*)	,,	Mile	200 48	,,	− 149·832	− 150 182	− 0·350
114 (*6*)	,,	Bridge	203·48	,,	− 637·601	− 638·303	− 0·702
5	,,	Embedded at Palāsner ..	203·94	,,	− 671·765	− 672·078	− 0·313
116 (*4*)	,,	Bridge	205·54	,,	− 743·196	− 743·546	− 0·350
118 (*2*)	,,	Bridge	206·68	,,	− 786 168	− 786 517	− 0·349
120 (*1*)	,,	Bridge	208·14	,,	− 831·483	− 831 870	− 0·387
58 (*35*)	46 K	Plinth	209·18	,,	− 876·587	− 876·982	− 0 395
59 (*31*)	,,	Bridge	209·59	,,	− 879·497	− 879 892	− 0·395

(*Continued*).

TABLE 3.—*Revision levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision−original). The sign + denotes that the height was greater and the sign −, less in 1929-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1929-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
(*Sehore to Dhūlia*) *old line 34, new 111.*—(*concld.*).							
61 (*33*)	46 K	Bridge ...	210·95	1877-78 & 83-84	− 795·665	− 796·099	− 0·434
65 (*31*)	"	Bridge	214·35		− 944·575	− 944·980	− 0·405
66 (*30*)	"	Embedded at Sulia-bandhara ...	214·46	"	− 941·418	− 941·868	− 0·450
68 (*28*)	"	Bridge	216·21	"	− 886·688	− 887·092	− 0·404
69 (*27*)	"	Bridge	216·93	"	− 939·570	− 939·948	− 0·378
75 (*22*)	"	Mile	221·64	"	−1080·437	−1080·718	− 0·281
79 (*20*)	"	Embedded at Shirpur	224·75	"	−1134·858	−1135·300	− 0·442
83 (*19*)	"	Bridge	226·98	"	−1118·676	−1119·260	− 0·584
96 (*18*)	"	Embedded at Dabasi	228·70	"	−1127·515	−1127·849	− 0·334
95 (*15*)	"	Culvert	233·66	"	−1049·098	−1049·456	− 0·358
98 (*13*)	"	Bridge	235·64	"	−1001·061	−1001·356	− 0·295
103 (*9*)	"	Bridge	239·80	"	− 884·083	− 884·336	− 0·253
7	"	Bridge	241·80	"	− 799·376	− 799·558	− 0·182
5	"	Step	243·04	"	− 804·835	− 805·005	− 0·170
6	"	Embedded at Sangir	243·06	"	− 803·440	− 803·614	− 0·174
4	"	Bridge ...	244·05	"	− 843·637	− 843·802	− 0·165
3	"	Bridge	244·95	"	− 841·081	− 841·235	− 0·154
107 (*2*)	"	Bridge	246·00	"	− 819·909	− 820·090	− 0·181
109 (*1*)	"	Mile	247·00	"	− 798·807	− 798·801	+ 0·006
150 (*85*)	46 L	Culvert ...	248·53	"	− 762·528	− 762·628	− 0·100
81	"	Mile	254·06	"	− 770·744	− 770·805	− 0·061
157 (*80*)	"	Embedded at Dhūlia	254·53	"	− 774·604	− 774·708	− 0·104
158 (*79*)	"	Bridge	254·80	"	− 770·212	− 770·300	− 0·088
107	"	S. B M. at Dhūlia ...	255·66	1909-10	− 759·376	− 759·433	− 0·057
(*Jhānsi to Bīna*) *old line 63B, new 109.*							
51	54 K	S B M. at Jhānsi ...	0·00	1906-07	0·000	0·000	0·000
112	"	Stone flooring ...	0·42	1921-22	− 16·256	− 16·255	+ 0·001
113	"	Well	0·50	"	− 17·067	− 17·066	+ 0·001
114	"	Rock in situ ...	1·28	"	− 53·945	− 53·952	− 0·007
116	"	Culvert ...	3·76	"	− 24·570	− 24·567	+ 0·003
117	"	Rock in situ ...	3·94	"	− 29·004	− 29·007	− 0·003
120	"	Rock in situ ...	5·97	"	+ 22·343	+ 22·357	+ 0·014
123	"	Interred at Simrabāri	9·99	"	− 1·876	− 1·885	− 0·009
124	"	Culvert .	12·04	"	+ 12·964	+ 12·944	− 0·020
126	"	Rock in situ ..	12·67	"	+ 44·450	+ 44·475	+ 0·025
127	"	Rock in situ ...	13·36	"	+ 71·592	+ 71·626	+ 0·034

(*Continued*).

TABLE 3.—*Revision levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision − original). The sign + denotes that the height was greater and the sign −, less in 1929-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1929-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
(*Jhānsi to Bīna*) *old line 63B, new 109*—(*concld.*).							
128	54K	Rock in situ ...	13·95	1921-22	+ 61·104	+ 61·130	+ 0·026
129	,,	Stone pillar .. .	14·50	,,	+ 61·450	+ 61·462	+ 0·012
141	,,	Bridge ...	32·92	,,	+ 135·534	+ 135·609	+ 0·075
142	,,	Rock in situ... .	34·53	,,	+ 187·345	+ 187·445	+ 0·100
143	,,	Boulder ...	35·80	,,	+ 232·535	+ 232·656	+ 0·121
36	54 L	Interred at M.S. Jhānsi 36	37·93	,,	+ 236·474	+ 236·604	+ 0·130
37	,,	Rock in situ	42·11	,,	+ 239·837	+ 240·008	+ 0·171
38	,,	Rock in situ... ...	44·82	,,	+ 219·414	+ 219·555	+ 0·141
39	,,	Rock in situ... ...	46·47	,,	+ 243·462	+ 243·608	+ 0·146
40	,,	Bridge ...	47·17	,,	+ 237·513	+ 237·650	+ 0·137
41	,,	Interred at M.S. Jhānsi 46	48·02	,,	+ 252·988	+ 253·123	+ 0·135
42	,,	Rock in situ	49·44	,,	+ 259·828	+ 259·957	+ 0·129
43	,,	Rock in situ ..	50·61	,,	+ 267·597	+ 267·719	+ 0·122
44	,,	Bridge	50·90	,,	+ 256·160	+ 256·279	+ 0·119
45	,,	Rock in situ	51·97	,,	+ 264·147	+ 264·258	+ 0·111
46	,,	Rock in situ . .	53·39	,,	+ 276·947	+ 277·053	+ 0·106
47	,,	Rock in situ ...	54·42	,,	+ 274·306	+ 274·405	+ 0·099
48	,,	Rock in situ	55·53	,,	+ 324·256	+ 324·354	+ 0·098
49	,,	Interred at M.S. Jhānsi 56	58·07	,,	+ 312·749	+ 312·840	+ 0·091
50	,,	Police hospital ...	58·76	,,	+ 321·140	+ 321·232	+ 0·092
51	,,	Municipal office	59·03	,,	+ 327·010	+ 327·108	+ 0·098
52	,,	Police station ...	59·06	,,	+ 324·572	+ 324·669	+ 0·097
53	,,	Temple	59·11	,,	+ 325·578	+ 325·673	+ 0·095
18	,,	Embedded at Bīna ...	101·17	1898-99	+ 503·741	+ 503·741	0·000
(*Gwalior to Jhānsi*) *old line 63A, new 109A.*							
31	54 J	S.B.M. at Gwalior ...	0·00	1905-06	0·000	0·000	0·000
34	,,	Embedded at Sithauli R.S.	4·47	1906-07	+ 4·404	+ 4·402	− 0·002
43	,,	Embedded at Antri R.S.	15·16	,,	+ 99·018	+ 99·132	+ 0·114
9	54K	Ry. platform .	25·55	,,	− 53·908	− 54·024	− 0·116
10	,,	Embedded at Dabra R.S.	25·61	,,	− 57·656	− 57·716	− 0·060
20	,,	Ry. platform ...	38·62	,,	− 46·293	46·356	− 0·063
21	,,	Embedded at Sonāgir R.S.	38·66	,,	− 51·019	− 51·080	− 0·061
22	,,	Ry. platform ...	38·69	,,	− 46·328	− 46·395	− 0·067
26	,,	Ry. platform ...	46·19	,,	+ 128·639	+ 128·615	− 0·024
47	,,	Stone flooring ...	62·36	,,	+ 138·432	+ 138·334	− 0·098
43	,,	Ry. platform ...	62·95	,,	+ 117·484	+ 117·449	− 0·035
44	,,	Ry. platform ...	63·06	,,	+ 117·448	+ 117·344	− 0·104
48	,,	Stone flooring ..	63·49	,,	+ 123·627	+ 123·543	− 0·084
49	,,	Stone step	64·08	,,	+ 114·332	+ 114·232	− 0·100
50	,,	Stone step	64·12	,,	+ 114·281	+ 114·186	− 0·095
51	,,	S.B.M. at Jhānsi ...	64·16	,,	+ 115·079	+ 114·985	− 0·094

(*Continued*).

TABLE 3.—*Revision levelling*—(*contd.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision − original). The sign + denotes that the height was greater and the sign −, less in 1930-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1930-31 (un-adjusted)	
			miles		*feet*	*feet*	*feet*
(*Tīnpahār to Pīrpainti*) *old line 74M.*							
124 (55)	72 P	Wall ...	0·00	1929-30	0·000	0·000	0·000
125 (65) (54)	,,	Masonry pillar	0·01	,,	+ 5·382	+ 5·343	− 0·039
208	72 O	Bridge ...	0·67	,,	− 9·604	− 9·574	+ 0·030
209	,,	Bridge ...	1·19	,,	− 3·622	− 3·561	+ 0·061
210	,,	Bridge ...	1·89	,,	+ 7·951	+ 8·053	+ 0·102
211	,,	Bridge ...	4·24	,,	+ 7·541	+ 7·736	+ 0·195
212	,,	Masonry pillar	5·98	,,	− 2·927	− 2·699	+ 0·228
213	,,	Bridge ...	7·98	,,	− 16·182	− 15·869	+ 0·313
214	,,	Bridge ...	10·41	,,	− 1·068	− 0·753	+ 0·315
215	,,	Bridge ...	12·47	,,	− 8·520	− 8·144	+ 0·376
216	,,	Masonry pillar	14·66	,,	− 10·809	− 10·429	+ 0·380
217	,,	Bridge ...	15·17	,,	− 16·467	− 16·065	+ 0·402
218	,,	Masonry pillar	18·42	,,	+ 16·634	+ 17·208	+ 0·574
219	,,	Bridge	21·27	,,	− 9·531	− 8·851	+ 0·680
220	,,	Ry. platform	23·38	,,	+ 2·541	+ 3·326	+ 0·785
221	,,	Masonry pillar	23·43	,,	+ 3·013	+ 3·802	+ 0·789
222	,,	Ry. platform	23·48	,,	+ 2·460	+ 3·250	+ 0·790
223	,,	Bridge ...	25·32	,,	− 6·069	− 5·152	+ 0·917
224	,,	Bridge	30·60	,,	− 5·011	− 3·877	+ 1·134
225	,,	Masonry pillar	32·83	,,	+ 1·207	+ 2·440	+ 1·233
226	,,	Ry. platform	38·05	,,	+ 39·862	+ 41·265	+ 1·403
227	,,	Flooring	38·11	,,	+ 41·143	+ 42·545	+ 1·402
228	,,	Masonry pillar	38·16	,,	+ 45·867	+ 47·270	+ 1·403
(*Pīrpainti to Purnea*) *old line 74M, and 73, new 74P.*							
228	72 O	Masonry pillar	0·00	1929-30	0·000	0·000	0·000
227 (64)	,,	Step ...	2·30	,,	− 48·949	− 48·962	− 0·013
230 (63)	,,	Masonry pillar	2·54	,,	− 59·831	− 59·823	+ 0·008
51	,,	Mileplate	20·90	1871-72	− 49·391	− 50·723	− 1·332
48	,,	Mileplate	22·90	,,	− 47·495	− 49·183	− 1·688
47	,,	Mileplate	23·91	,,	− 49·738	− 51·107	− 1·369
38	,,	Culvert ...	29·55	,,	− 49·227	− 48·719	+ 0·508
37	,,	Mileplate	30·00	,,	− 41·151	− 42·598	− 1·447
35	,,	Mileplate	31·02	,,	− 42·549	− 42·996	− 0·447
34	,,	Mileplate	32·03	,,	− 40·916	− 40·411	+ 0·505
32	,,	Mileplate	33·03	,,	− 42·128	− 42·077	+ 0·051
27	,,	Mileplate	38·46	,,	− 38·834	− 38·906	− 0·072
13	,,	Embedded at Purnea	39·29	,,	− 41·602	− 41·153	+ 0·449
177	,,	S.B.M. at Purnea	39·69	1909-10	− 39·012	− 38·557	+ 0·455

(*Continued.*)

TABLE 3.—*Revision levelling*—(*concld.*).

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

Bench-marks of the original levelling that were connected during the revisionary operations			Distance from starting bench-mark	Difference between orthometric heights, above (+) or below (−) the starting bench-mark			Difference (revision − original). The sign + denotes that the height was greater and the sign −, less in 1930-31 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1930-31 (unadjusted)	
			miles		*feet*	*feet*	*feet*
(Mandalay to Sagaing) old line 89.							
2	93 B	S.B.M. at Mandalay	0·00	1909-10	0·000	0·000	0·000
1	,,	Rock	0·02	,,	− 3·207	− 3·211	− 0·004
38	,,	Culvert	0·88	1923-24	− 10·343	− 10·317	+ 0·026
5	,,	Culvert	1·07	1909-10	− 10·847	− 10·767	+ 0·080
54	93 C	Stone	3·10	,,	− 6·469	− 6·429	+ 0·040
63	,,	Brick platform ...	9·50	1923-24	− 10·502	− 10·534	− 0·032
148 (*66*)	,,	Embedded at Amarapura	12·18	,,	− 21·148	− 21·118	+ 0·030
68	,,	River crossing pillar	13·42	,,	+ 24·414	+ 24·469	+ 0·055
1	84 O	River crossing pillar	13·83	1909-10	+ 16·974	+ 17·231	+ 0·257
2	,,	Embedded at Sagaing	14·08	,,	− 21·101	− 20·884	+ 0·217
3	,,	Bridge	16·44	,,	− 1·382	− 1·153	+ 0·229
4	,,	Embedded at Ywataung ..	17·32	,,	+ 7·957	+ 8·177	+ 0·220

TABLE 4.—*List of triangulation stations connected by spirit-levelling season 1929-31.*

Name of station	Height above mean sea-level		Difference (Trian. − Lev.)	Remarks
	Spirit-levelling	Triangulation		
	feet	*feet*	*feet*	
Khānpisura Meridional Series				
Dhanvār (Dhānvad) H.S.	1,162·727	1,177	+ 14	Lower mark (on stone boulder).
Lat. 20° 53′ 03″·31				
Long. 75 36 02·43				
Singārchori H.S.	2,889·758	2,889	− 1	Upper mark-stone.
Lat. 22° 24′ 39″·91				
Long. 75 40 28·44				
Thikri (Thīkri) H.S.	850·920	849	− 2	Upper mark-stone.
Lat. 22° 01′ 02″·77				
Long. 75 24 49·98				
Buldāna Series				
Kati (Kāti) S.	959·943	966	+ 6	Upper mark-stone.
Lat. 20° 50′ 10″·02				
Long. 76 16 52·35				
Khandoba S.	1,033·112	1,037	+ 4	Upper mark-stone.
Lat. 20° 45′ 45″·76				
Long. 76 34 46·42				
Ashta Series				
Baroli H.S.	1,878·389	1,876	− 2	Upper mark-stone.
Lat. 22° 57′ 53″·59				
Long. 76 17 38·05				
Budhon Meridional Series				
Maharājpur H.S.	1,022·330	1,015	− 7	Ground mark (on rock in situ.)
Lat. 25° 53′ 54″·44				
Long. 78 14 13·09				

(*Continued*).

LENGTH OF LEVELLING STAVES 1930-31

Chart XVIII

Scale 2 Small Squares=0·001 Feet

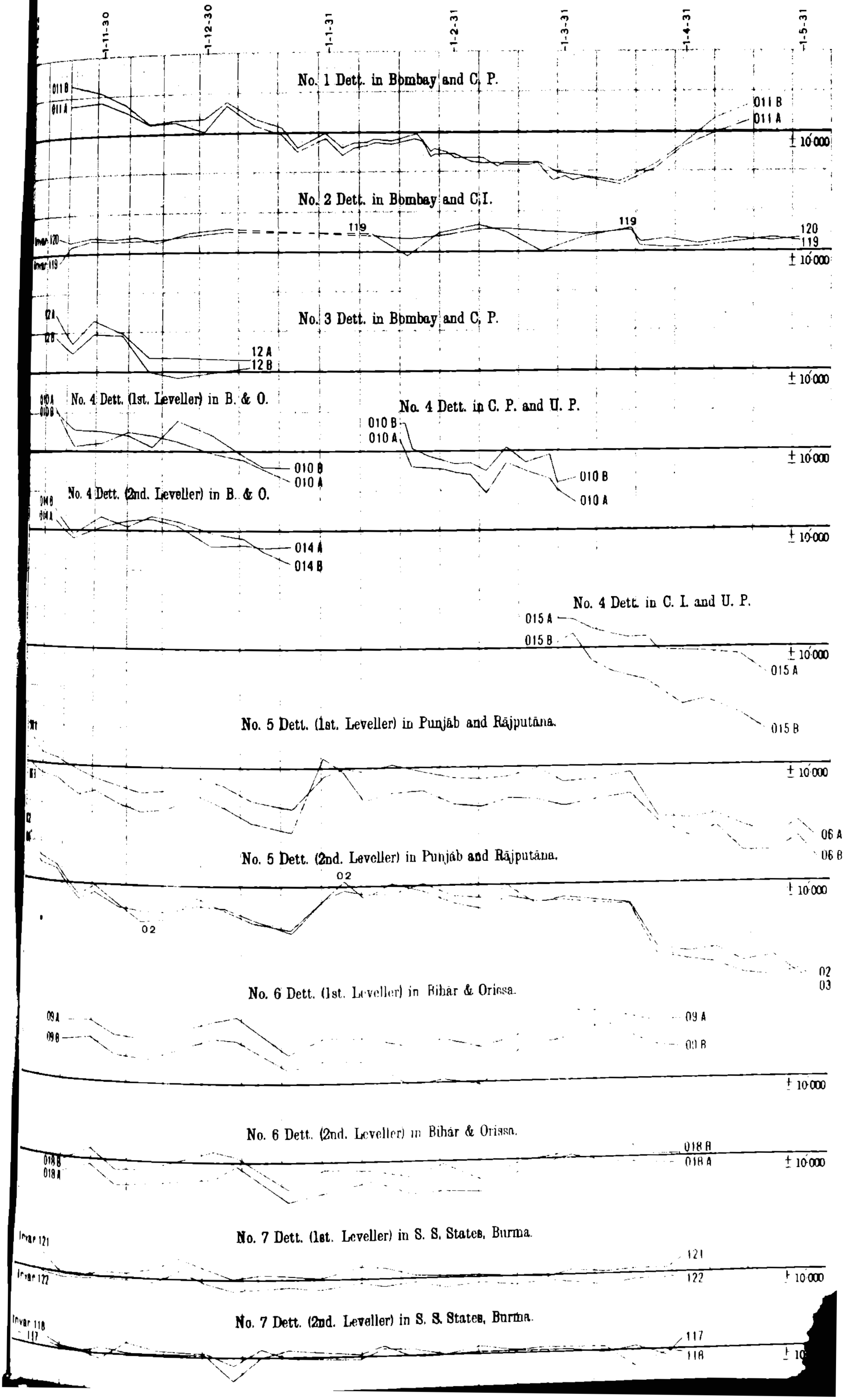


TABLE 4.—*List of triangulation stations connected by spirit-levelling, season 1930-31.*—(*concld.*).

Name of station	Height above mean sea-level Spirit-levelling	 Trian-gulation	Difference (Trian. – Lev.)	Remarks
	feet	*feet*	*feet*	
Great Salween Series				
Kengtung South End Base Station Lat. 21° 18′ 15″·52 Long. 99 36 33·18	2,586·479	2,586	0	Upper mark (Top of brass cylinder).
East Coast Series				
Cuttack (Bārabāti) H.S. Lat. 20° 29′ 00″·68 Long. 85 52 01·43	133·323	132	– 1	Top mark-stone.

CHAPTER VIII

THE MAGNETIC SURVEY

BY CAPTAIN G. BOMFORD, R.E.

1. **Summary.**—In addition to the usual programme of observations at the Dehra Dūn observatory (and at Alībāg under the Director-General of Observatories), a field detachment occupied 37 repeat stations, covering about half the area of the magnetic survey.

The observations of horizontal force made at Dehra Dūn during 1920-30 have been reconsidered and final values are now published.

2. **Dehra Dun Observatory, 1930.**—The usual programme was carried out consisting of a continuous magnetographic record of declination, horizontal force and vertical force, daily observations of dip, and bi-weekly observations of declination and horizontal force. Five severe magnetic storms were recorded during the year, on March 12th, June 16th, Sept. 18th, Oct. 17th and Dec. 3rd and 4th.

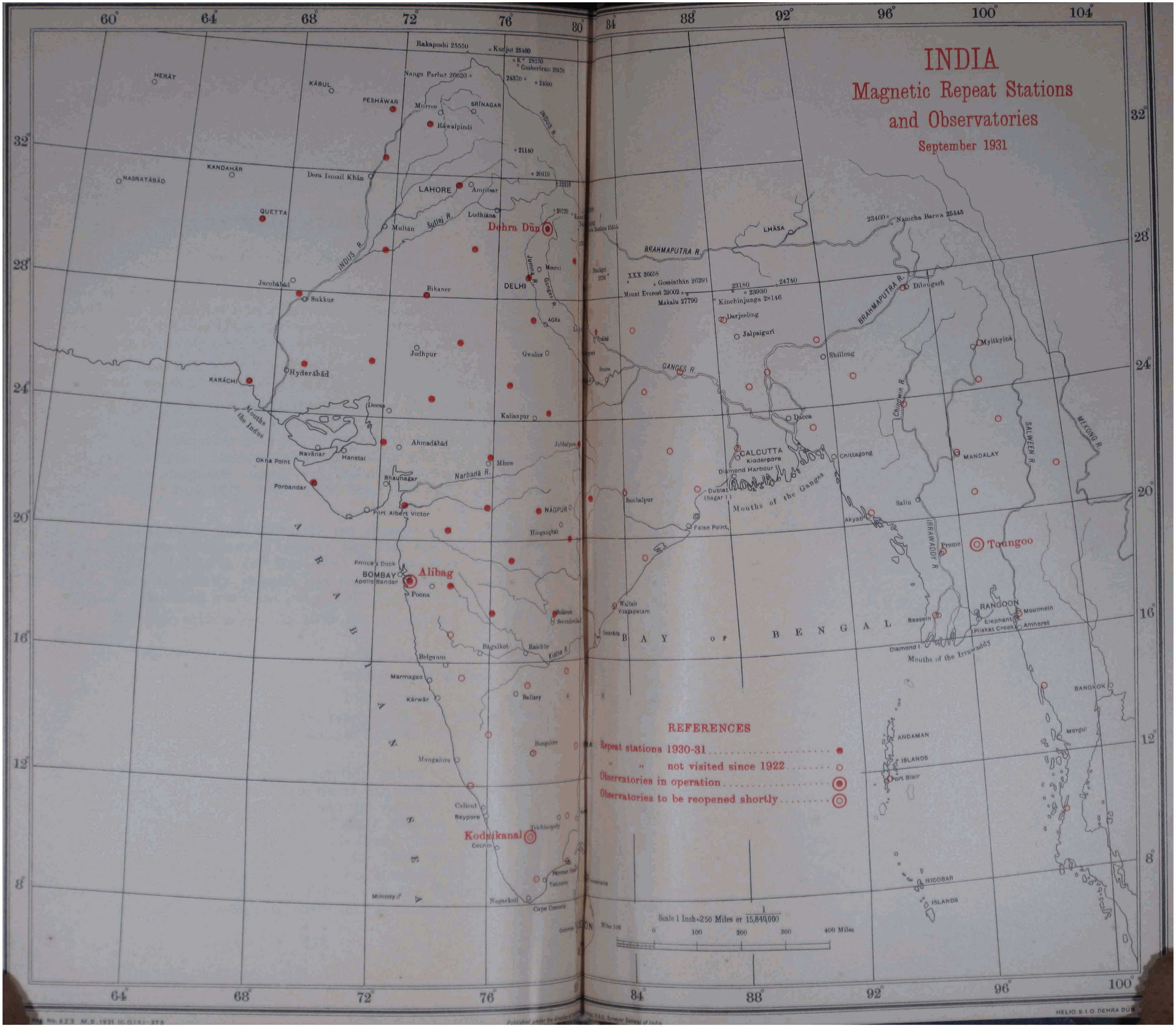
Subsoil water percolated into the passage round the underground magnetograph room between July 29th and Aug. 16th. In the months of October and November 1930, the H. F. and declination clock frequently stopped, causing considerable loss in both traces. The clock was taken out and thoroughly cleaned.

The mean scale values for 1930 for an ordinate of 1/25-inch were :—

Horizontal force	...	4·26 gammas
Vertical force	...	9·34 to 10·58 gammas
Declination	...	1·03 minutes.

The mean temperature for the year was 27°·0 C with maximum and minimum values of 27°·5 C and 26°·1 C, the temperature of reduction being 27°·0 C.

Table 1 shows the mean monthly values of the magnetic collimation, the distribution constants $P_{1\cdot2}$ and $P_{2\cdot3}$, the accepted value of log $(1+P/r^2+Q/r^4)^{-1}$, and the values of m for magnet No. 17. Table 2 gives the mean monthly observed values of the declination and horizontal force base-lines. Table 3 shows the mean monthly values of the elements for 1929 and 1930, and the annual change for the period. The mean hourly deviations from the monthly means are given in Tables 4 to 7. Table 8 gives the classification of the magnetic character of all days in 1930. The



INDIA
Magnetic Repeat Stations and Observatories
September 1931

REFERENCES

Repeat stations 1930-31 .... ●

" " not visited since 1922 .... ○

Observatories in operation .... ◉

Observatories to be reopened shortly .... ◎

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

Reg. No. 423 M.D. 1931 (C.G.)(S.)-375

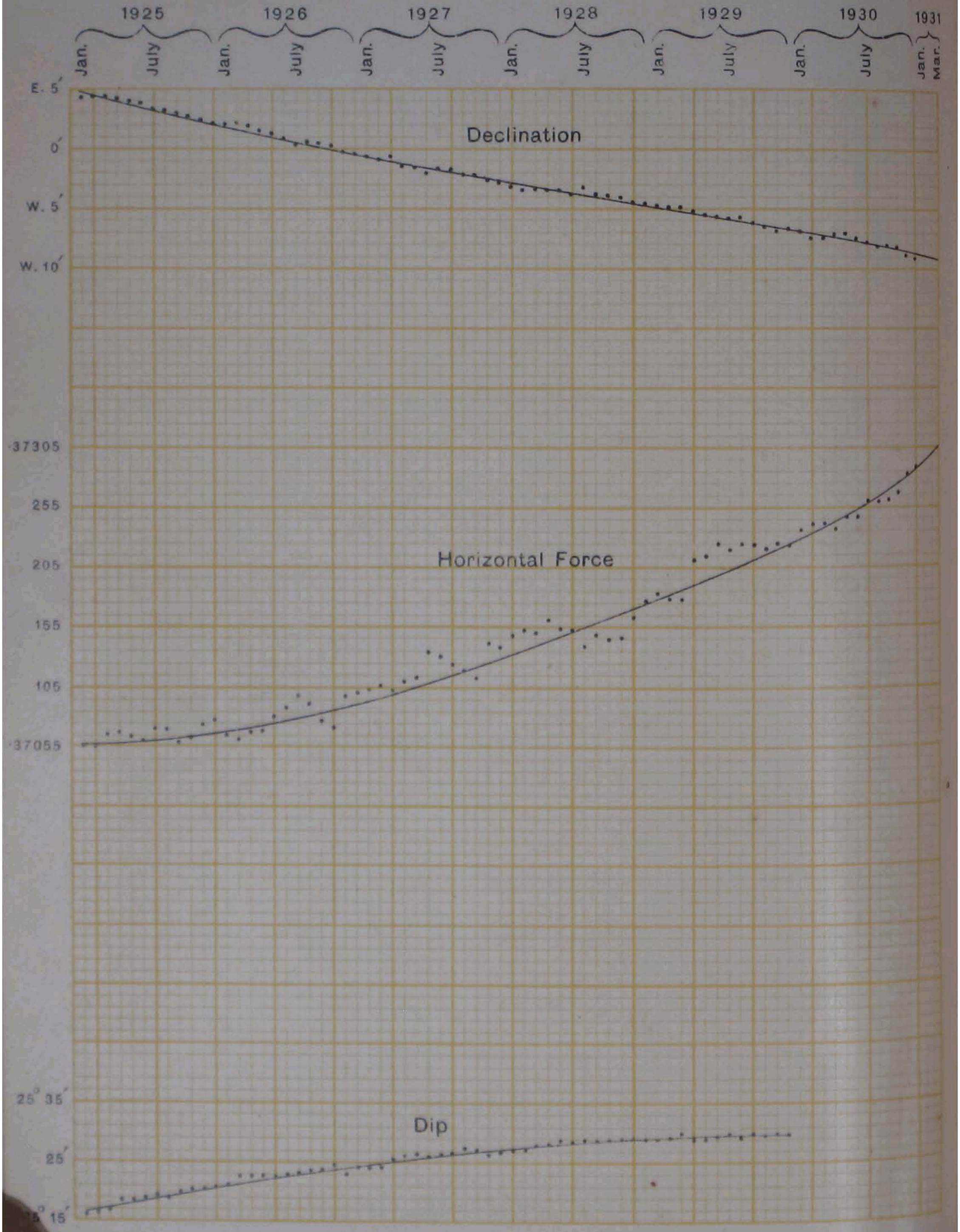
Published under the direction of ... D.S.O., Surveyor General of India

HELIO. S.I.O. DEHRA DUN

Magnetic Elements at Alibag

1925–30

Plate XX



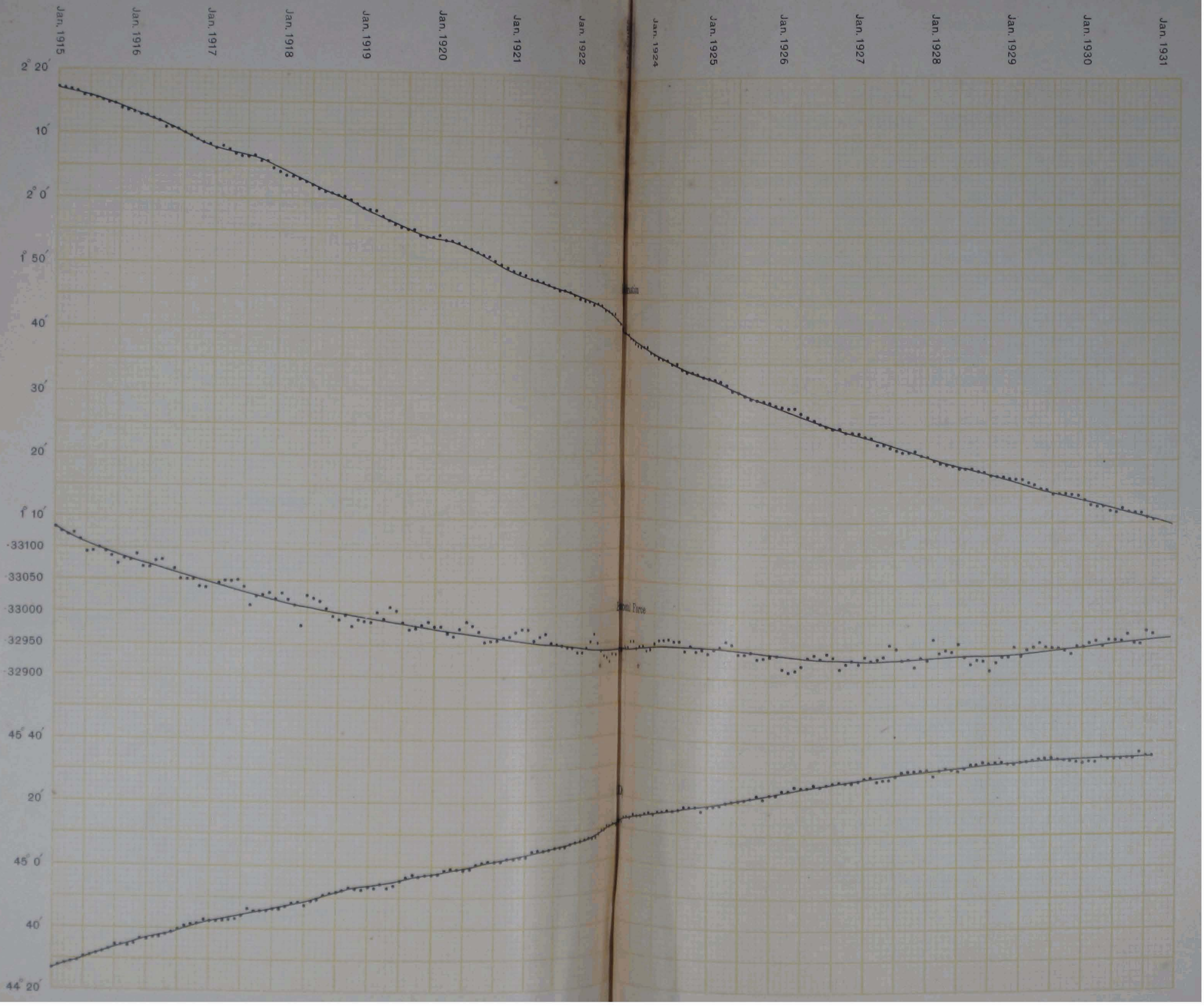
Reg No.446.M.D.31–350.

H.S.I.O. Dehra Dun

Plate XXI

Magnetic Element Dehra Dun

1915



symbols C, S, M, G and VG there used are those which have been employed in all the Survey of India records. They correspond with the International (De Bilt) classification somewhat as follows:—

0 De Bilt = C and part of S.
1 De Bilt = Part of S, and M.
2 De Bilt = G and VG.

3. Field repeat stations, 1930-31.—A field detachment was formed under Mr. Shyam Narain, B.SC., who observed declination, force and dip at all the repeat stations which are dependent only on the Dehra Dūn and Alībāg observatories. It had been hoped to reopen the Kodaikānal and Toungoo (Burma) observatories during 1931-32 and to observe the remaining repeat stations that year, but financial stringency has postponed the programme, and its early completion appears to be so doubtful that results for the north of India are now published without waiting for the completion of the rest of the survey.

In addition to Mr. Shyam Narain the detachment consisted of 1 recorder and 8 khalāsis. Work started at Lahore on Oct. 25th 1930, and was completed at Kāthgodām on March 24th, 1931. The instruments used were magnetometer No. 4 and dip circle No. 136.

The instruments worked satisfactorily and the usual degree of accuracy was maintained, except that the dip needles showed very wide variations, presumably on account of imperfection in their pivots, although no defect has been definitely detected. The dip observations can only be relied on as correct to 10′. Table 9 gives the monthly mean values of m and log $(1+P/r^2+Q/r^4)^{-1}$ for magnetometer No. 4. They were satisfactorily constant. Log $\pi^2 K$ was determined before the field season.

The results of comparisons with the standard instruments at Dehra Dūn and Alībāg are given in Table 10. The accepted corrections to the field values of declination are –0′·4, to H.F. + 9γ, and to dip nil. The reason for applying no correction to dip is the wide variation in the differences between needles at the different field stations: the instrumental error was clearly not constant.

The field observations have been computed and reduced to epoch 1931·0 during recess, under the supervision of Mr. B. L. Gulatee, M.A. The Meteorologist, Bombay, who is in charge of the Alībāg observatory, has supplied data from which, in conjunction with the Dehra Dūn data, the diurnal variation and perturbation have been calculated at the required hours. The annual changes and normal values of the elements at Alībāg have been taken from curves (Plate XX) plotted from monthly mean values supplied by the Meteorologist, Bombay. Similar curves for Dehra Dūn are given in Plate XXI. The results at the repeat stations are given in Tables 11 to 14. The values of the elements at the field stations of the original survey have been brought up to date by means of these values of the annual change and are shown by contour lines on Plates XXIV to XXVII.

4. Dehra Dun Observatory, 1920-30.—The reduction of observations of horizontal force involves the adoption of accepted values of the moment and distribution factors of the magnet, which cannot always be decided until a considerable number of further observations have been made. It is consequently necessary to reconsider past work from time to time, and to publish final values. The period from the beginning of the survey until 1920 is covered by Records Volume No. XIX. The present report deals with the Dehra Dūn observatory between 1920 and 1930. Its preparation has been supervised by Mr. B.L. Gulatee, M.A.

At Dehra Dūn, the observations of H.F. have been complicated by an appearance of irregular increase in the moment of the magnet, and by an apparent annual change of moment from summer to winter (see Geodetic Report Vol. VI, page 10). The latter has been shown to be due to a change (or error) in the accepted temperature coefficient, but no satisfactory explanation has been found for the apparent increases of *m*.

The magnetic moment of the magnet (m_t) at any temperature t°C is related to its moment at 0°C by the formula—

$$m_t = m_0\ (1 - \alpha t - \beta t^2).$$

The values of α and β obtained at Kew Observatory in Dec. 1901 were $\alpha = +36{\cdot}6 \times 10^{-5}$, $\beta = +9{\cdot}5 \times 10^{-7}$.

The following table shows the values which Mr. Gulatee has now obtained:—

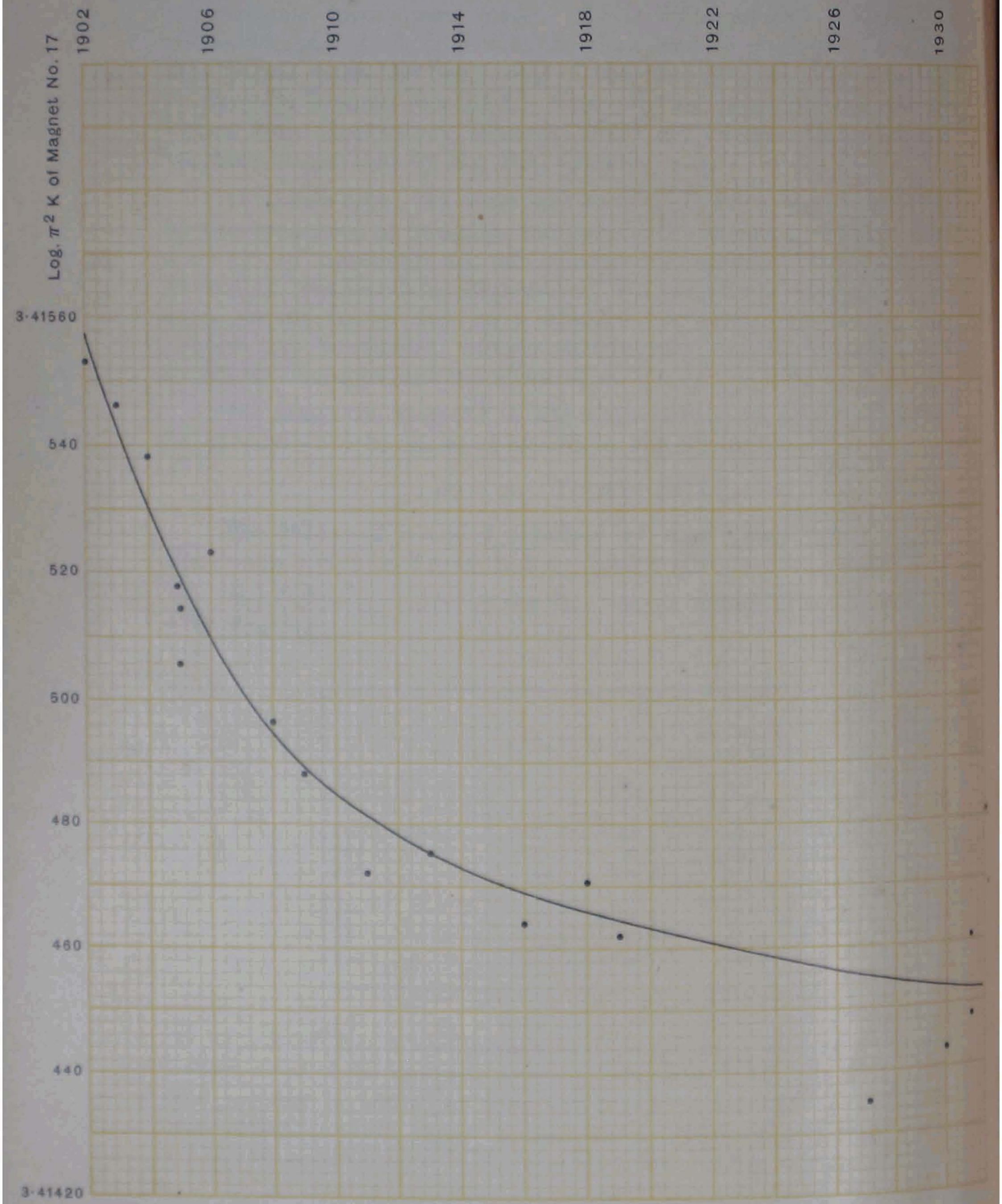
	$\alpha \times 10^{-5}$	$\beta \times 10^{-7}$	$(\alpha + 2\beta t)\,10^{-5}$ at $t = 23\frac{1}{2}$°C.
1st measure ...	+31·3	+23·3	42·3
2nd " ...	+35·7	+20·5	45·4
3rd " ...	+36·0	+16·9	44·0
4th " ...	+37·5	+17·4	45·7
5th " ...	+34·2	+16·6	42·0
6th " ...	+38·0	+14·7	44·9

Each of the above measures depends on 5 sets of deflections measured at three temperatures viz., about 10°, 34° and 47°C. The last column is added to show the temperature coefficient at 23½°C the normal annual mean temperature. The value given by the 1901 values of α and β is 41·1, so that the reality of the change is

Plate XXII

Log. π^2 K of Magnet No. 17

Assuming Log. π^2 K of S. G. bar = 3·75313 in 1905
298 ,, 1922
298 ,, 1930



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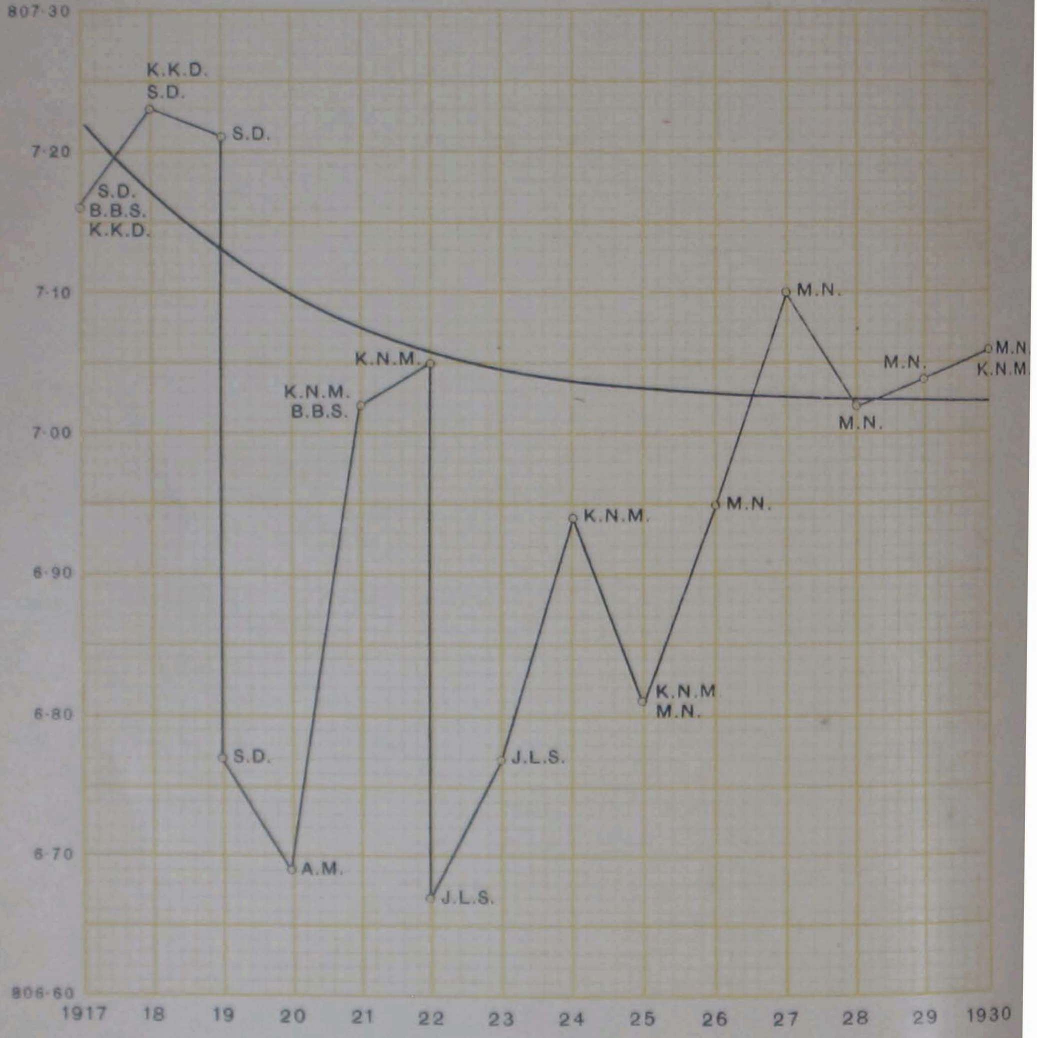
H.S.I.O. Dehra Dūn

Magnetic Moment
of
Magnet No. 17

Plate XXIII



Reg.No.449.M.D.31-350.

H.S.I.O.Dehra Dūn.

quite apparent. The acceptance of the above mean values of a and β results in the disappearance of the decrease of moment from winter to summer, but on the average produces a small variation of opposite sense. It is possible that the values now obtained are a little too high.

The moment of inertia of magnet No. 17 has been twice re-determined during the present year. Plate XXII shows the variation of log $\pi^2 K$ since 1902 (making assumptions regarding the moment of the standard gilt bar as described in Geodetic Report Vol. VI, page 10), and the smooth curve shows the values that are now accepted for 1920-30. In the earlier years the curve hardly differs appreciably from the values accepted in Records Vol. XIX. The 1927 value of log $\pi^2 K$ is considered unreliable.

The values obtained for the factor $(1 + P/r^2 + Q/r^4)^{-1}$ have varied widely from year to year (see Table 15). The factor is nearly unity, and so long as m remains more or less unchanged, it is clear that such wide variations cannot be real. A mean value of $\bar{1}$·99415 has therefore been accepted for its log throughout. Table 15 shows the observed values of log $(1 + P/r^2 + Q/r^4)^{-1}$, the accepted values of log $\pi^2 K$, and the values of m which result, using the new temperature constants. Similar information is given for magnetometer No. 5, which is used as a check. Its m shows a steady fall, log $(1 + P/r^2 + Q/r^4)^{-1}$ is reasonably constant, and the results should be reliable. But only comparatively few observations have hitherto been made with it.

The annual mean values of m of No. 17 are also shown in Plate XXIII, where it is noticeable that the irregular increases of m are not corrected. The observers' initials are entered on the chart. Two values are given in 1919, since there was a sudden fall in the month of October. The observer S.D. was experienced, and his results before and after the fall were consistent *inter se*. There is thus reason to suppose the fall to be real, especially as it is confirmed by the observer A.M. in 1920. Two values are also given in 1922, there being a change of observer, but the observations of J.L.S. were so irregular as to be of little value.

For calculating H three courses are possible—

(1) To accept the monthly mean values of m as observed.

(2) To accept the annual mean values of m.

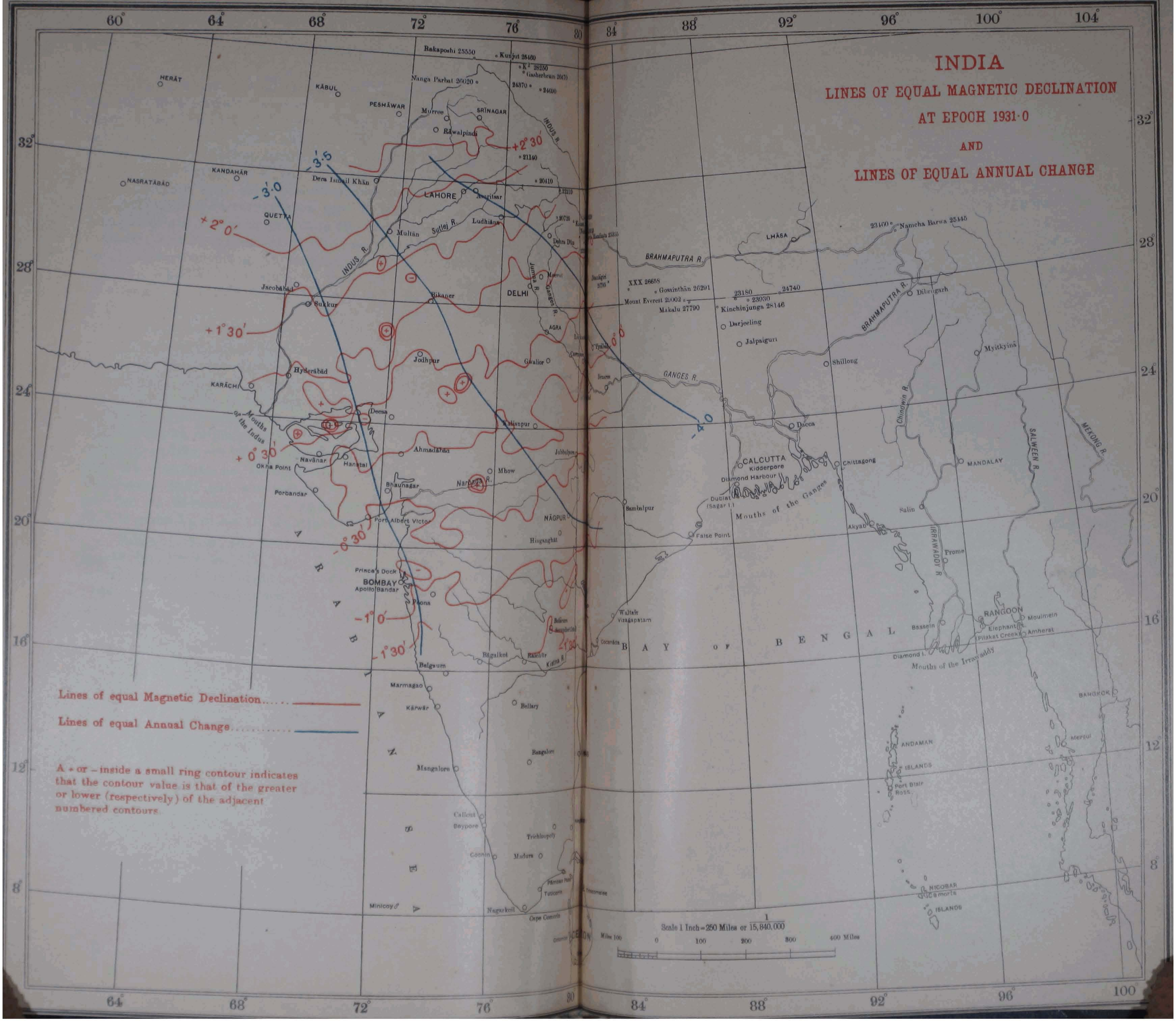
(3) To accept the values of m as given by some smooth curve such as that shown on Plate XXIII.

Course (1) has the advantage that ignorance of the true temperature coefficient will not introduce a fallacious annual variation of H. It has the disadvantage that a single month's observation may not give a very good value of m, but it is believed that systematic errors are far more serious than such casual errors as may be present in a monthly mean.

Course (3) has the advantage that the values of *m* used (or at any rate their variations from year to year) may be expected to be more correct than those given by other courses, but this does not necessarily result in better values of *H*. If all the error was known to lie in the vibration experiment, (3) would be the right course, but the great variations in the observed values of the distribution factor indicate that some observers have made systematic errors in the deflection observation also, and it is quite possible that the best cancellation is to be got from the acceptance of each observer's deflection and vibration experiments as they stand. Further, when two observers covering 18 months in 1919-20 have consistently obtained results 0·40 smaller than two observers in 1926-30 (confirmed by a third in 1931), it is right to admit the possibility of the magnet having unintentionally received such treatment as would cause an increase of *m*.

If observations had been made with the check magnetometer No. 5 in the very irregular years 1919-23, comparison of the annual mean values of *H* as given by it and by No. 17 would have been a good guide to the best course. Unfortunately check observations have only been made during the less irregular years 1924-30. Table 16 shows annual mean values of $H-32{,}000\gamma$ as given by No. 17 on the three different hypotheses, the annual means according to No. 5, and the discrepancies between the two magnetometers. The last line shows that the acceptance of a steadily falling curve has resulted in distinctly worse agreement between the instruments than is given by either of the other two courses.

Table 17 shows the final values of *m* of No. 17 from month to month for 1920 to 1930, and Table 18 shows the values of *H*, calculated in three ways as above. The first value, H_1, which results from the acceptance of the observed monthly mean *m*, is considered the most reliable, and this course is being followed henceforward.



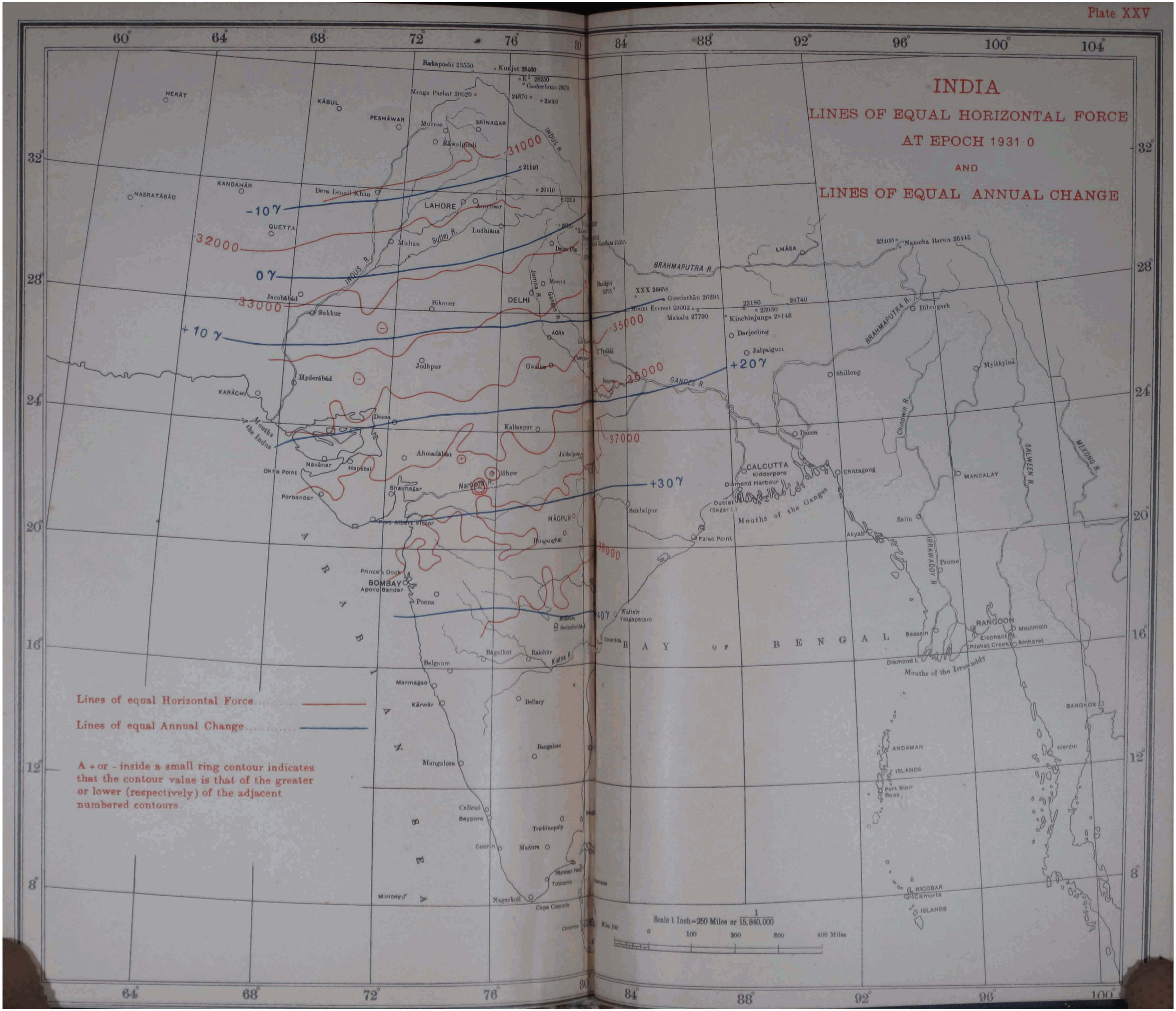
INDIA
LINES OF EQUAL MAGNETIC DECLINATION
AT EPOCH 1931·0
AND
LINES OF EQUAL ANNUAL CHANGE

Lines of equal Magnetic Declination ...... 🟥

Lines of equal Annual Change .... 🟦

A + or − inside a small ring contour indicates that the contour value is that of the greater or lower (respectively) of the adjacent numbered contours.

Plate XXV



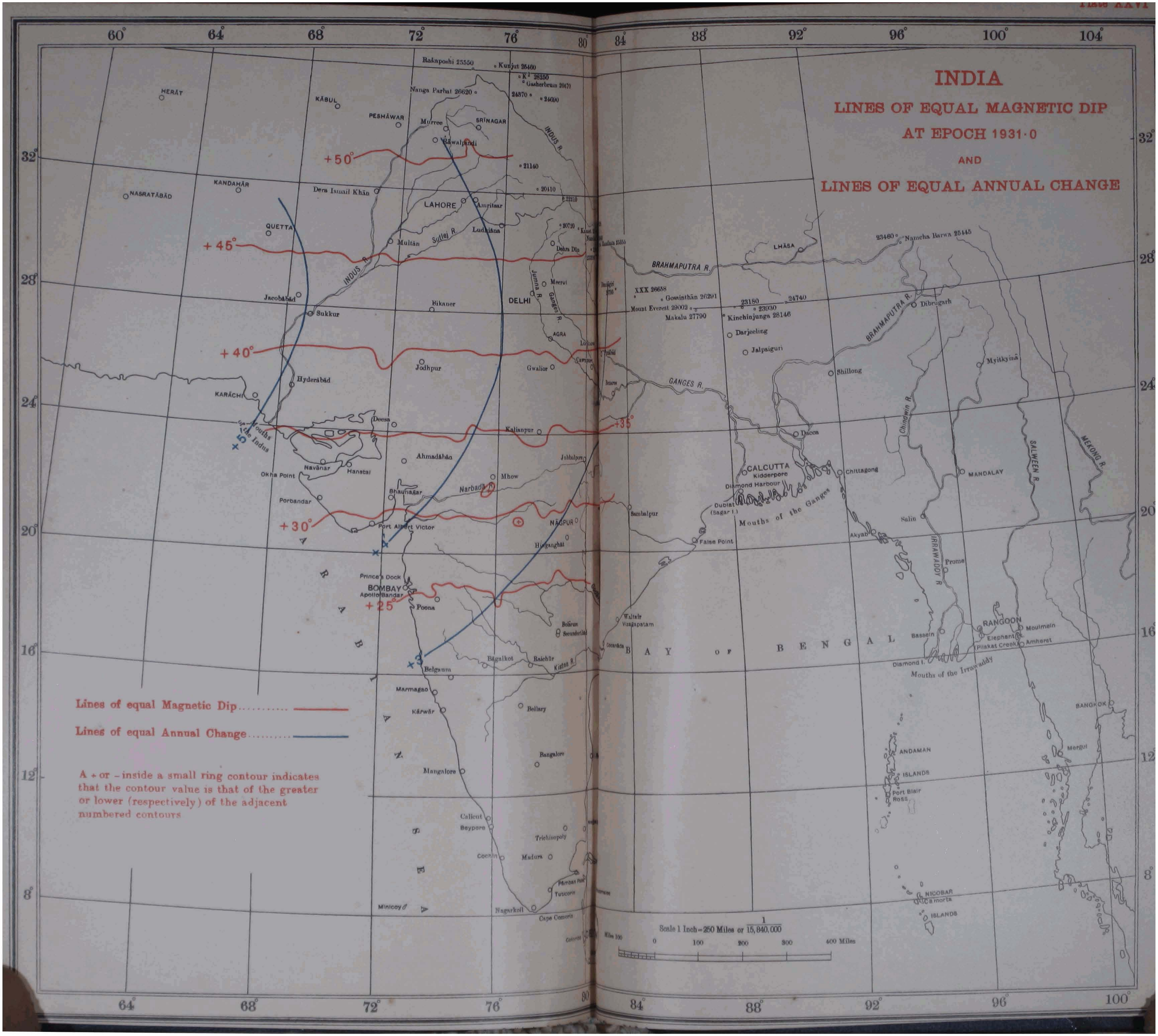
INDIA
LINES OF EQUAL HORIZONTAL FORCE AT EPOCH 1931·0 AND LINES OF EQUAL ANNUAL CHANGE

Lines of equal Horizontal Force..........

Lines of equal Annual Change..........

A + or - inside a small ring contour indicates that the contour value is that of the greater or lower (respectively) of the adjacent numbered contours.

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



INDIA
LINES OF EQUAL MAGNETIC DIP AT EPOCH 1931·0 AND LINES OF EQUAL ANNUAL CHANGE

Lines of equal Magnetic Dip ....

Lines of equal Annual Change ....

A + or − inside a small ring contour indicates that the contour value is that of the greater or lower (respectively) of the adjacent numbered contours

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

Plate XXVII

INDIA

LINES OF EQUAL TOTAL FORCE AT EPOCH 1931·0

A + or - inside a small ring contour indicates that the contour value is that of the greater or lower (respectively) of the adjacent numbered contours.

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

TABLE 1.—*Mean values of the constants of Magnetometer No. 17 in 1930.*

Month	Declination constants	H. F. constants				
	Mean magnetic collimation	Distribution factors			Mean values of *m*	
		$P_{1·2}$	$P_{2·3}$	Accepted value of $\log (1 + P/r^2 + Q/r^4)^{-1}$	Monthly means	Accepted *m*
	′ ″	cm²	cm²		C. G. S.	C. G. S.
January ...	− 6 19	5·91	7·75	1·99415 throughout	806·87	806·87
February ...	− 6 21	5·83	7·73		6·97	6·97
March ...	− 6 14	6·02	6·52		7·17	7·17
April ...	− 6 17	5·80	8·04		7·09	7·09
May ...	− 6 17	6·01	7·76		7·16	7·16
June ...	− 6 16	5·77	7·92		7·28	7·28
July ...	− 6 18	5·84	7·86		6·97	6·97
August ...	− 6 15	5·80	8·09		7·05	7·05
September	− 6 19	5·87	8·10		7·05	7·05
October ...	− 6 12	6·06	6·42		7·07	7·07
November	− 6 13	6·03	6·54		7·10	7·10
December	− 6 14	6·06	6·67		806·99	806·99

TABLE 2.—*Base-line values of Magnetographs at Dehra Dūn in 1930 from Magnet No. 17.*

Month	Declination	Horizontal force
	Observed mean value of base-line	Observed mean value of base-line
	° ′	C. G. S.
January ...	0 26·1	0·32673
February ...	25·9	672
March ...	26·4 *a* 25·6 *b* 26·6 *c*	679
April ...	26·1	676
May ...	26·1	677
June ...	26·1 *d* 27·2 *e*	681
July ...	27·0 *f* 26·5 *g*	672
August ...	26·9	677
September ...	27·1	675
October ...	27·7	672
November ...	27·3	670
December ...	0 27·0	0·32669

N. B.—The above values have been accepted.

a. Up to 10^{h} on 10th.

b. Up to 10^{h} on 24th.

c. From 11^{h} on 24th.

d. Up to 10^{h} on 27th.

e. From 11^{h} on 27th.

f. Up to 10^{h} on 21st.

g. From 11^{h} on 21st.

TABLE 3.—*Monthly mean values of the Magnetic elements and their annual changes, Dehra Dūn, 1929-30.*

Month	Horizontal force 0·32000 C. G. S. +			Declination E 1° +			Dip N 45° +			Vertical force 0·33000 C.G.S. +		
	1929	1930	Annual change	1929	1930	Annual change	1929	1930	Annual change	1929	1930	Annual change
	γ	γ	γ	′	′	′	′	′	′	γ	γ	γ
January	941	952	+ 11	17·0	13·6	− 3·4	33·1	32·8	− 0·3	576	586	+ 10
February	961	958	− 3	17·0	12·9	− 4·1	33·0	33·7	+ 0·7	590	610	+ 20
March	945	963	+ 18	16·9	12·5	− 4·4	33·8	33·3	− 0·5	590	608	+ 18
April	951	954	+ 3	16·3	12·5	− 3·8	33·8	34·9	+ 1·1	603	630	+ 27
May	953	963	+ 10	16·0	11·9	− 4·1	33·9	34·3	+ 0·4	607	627	+ 20
June	949	964	+ 15	15·3	11·6	− 3·7	34·3	34·4	+ 0·1	623	630	+ 7
July	943	962	+ 19	15·1	12·1	− 3·0	34·6	34·3	− 0·3	623	626	+ 3
August	*	972	...	14·8	11·6	− 3·2	34·7	34·7	0·0	*	644	...
September	*	957	...	14·5	11·5	− 3·0	34·1	34·5	+ 0·4	*	625	.
October	940	956	+ 16	14·5	11·5	− 3·0	34·0	36·3	+ 2·3	605	659	+ 54
November	937	976	+ 39	14·4	10·9	− 3·5	33·9	35·5	+ 1·6	601	664	+ 63
December	935	973	+ 38	14·1	10·3	− 3·8	33·5	35·5	+ 2·0	589	662	+ 73
Means	946	963	+ 17	15·5	11·9	− 3·6	33·9	34·5	+ 0·6	601	631	+ 30

γ = 0·00001 C. G. S.

* Magnetometer No. 17 was sent to M. I. O. for repairs.

TABLE 4.—*Declination at Dehra Dūn in 1930* (determined from 5 selected quiet days in each month).

Month	monthly Mean*	Hourly mean *minus* monthly 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 ...	13·6	+0·2	+0·2	+0·1	−0·1	−0·2	−0·2	−0·4	−0·5	+0·5	**+2·1**	+1·7	−0·2	−1·1	**−1·2**	−1·0	−0·6	+0·1	+0·2	+0·1	+0·3	+0·1	+0·2	+0·2	0·0	+0·1
February ...	12·9	+0·4	+0·2	+0·1	0·0	−0·1	−0·3	−0·3	−0·3	+0·2	+1·0	**+1·3**	+1·0	−0·2	**−0·8**	−0·7	−0·5	−0·4	−0·5	−0·3	−0·1	−0·2	+0·1	+0·2	+0·3	+0·1
March ...	12·5	+0·1	+0·1	+0·2	−0·2	+0·2	−0·1	0·0	+0·9	+2·1	**+2·3**	+1·5	−0·4	−1·9	**−2·3**	−1·6	−0·8	−0·3	+0·1	+0·1	−0·1	0·0	0·0	+0·1	+0·4	+0·2
October ...	11·5	+0·2	+0·3	+0·1	+0·1	−0·1	0·0	0·0	+0·7	+2·1	**+2·2**	+1·1	−0·4	−1·9	**−2·3**	−1·7	−0·7	0·0	+0·1	0·0	−0·1	0·0	−0·1	+0·1	+0·2	+0·3
November ...	10·9	+0·3	0·0	0·0	0·0	−0·1	−0·2	−0·5	−0·4	+0·3	**+0·7**	+0·4	−0·3	**−0·6**	−0·3	+0·1	+0·4	+0·1	−0·1	0·0	−0·1	−0·1	−0·1	−0·1	0·0	0·0
December ...	10·3	+0·1	+0·1	+0·1	+0·1	−0·1	−0·1	−0·3	**−0·5**	−0·4	0·0	+0·2	−0·4	−0·5	−0·1	+0·2	**+0·5**	+0·4	+0·3	+0·2	+0·3	+0·1	0·0	+0·1	+0·1	+0·1
Winter Means ...	12·0	+0·2	+0·2	+0·1	0·0	−0·1	−0·2	−0·3	0·0	+0·8	**+1·4**	+1·0	−0·1	−1·0	**−1·2**	−0·8	−0·3	0·0	0·0	0·0	0·0	0·0	0·0	+0·1	+0·2	+0·1
April ...	12·5	+0·3	+0·2	+0·3	+0·4	+0·2	+0·2	+1·0	+1·8	**+3·2**	+2·8	+1·5	−0·6	−2·1	**−2·7**	−2·6	−1·6	−1·0	−0·3	−0·4	−0·4	−0·1	+0·1	+0·1	+0·1	+0·4
May ...	11·9	+0·4	+0·4	+0·5	+0·5	+0·4	+0·8	+1·9	+2·6	**+2·8**	+2·0	+0·7	−1·1	−2·1	**−2·5**	−2·2	−1·9	−1·0	−0·5	+0·1	−0·6	−0·6	−0·7	−0·6	−0·4	−0·1
June ...	11·6	+0·1	+0·2	+0·1	+0·2	+0·4	+0·6	+1·8	+2·8	**+3·0**	+2·6	+1·3	−0·6	−1·6	−2·5	**−2·6**	−2·2	−1·5	−0·7	−0·2	−0·7	−0·9	−0·6	−0·5	−0·3	0·0
July ...	12·1	−0·2	+0·1	+0·2	+0·4	+0·3	+0·4	+1·6	+2·1	**+2·2**	+1·8	+0·9	−0·2	−1·1	−1·6	**−1·8**	−1·4	−0·9	−0·5	−0·3	−0·4	−0·8	−0·7	−0·6	−0·3	−0·3
August ...	11·6	+0·4	+0·4	+0·6	+0·7	+0·7	+0·7	+1·7	**+2·5**	+2·5	+1·6	+0·4	−1·0	−1·8	**−2·5**	−2·4	−1·7	−1·0	−0·6	−0·4	−0·2	−0·6	−0·5	−0·2	−0·2	+0·2
September ...	11·5	+0·1	+0·2	+0·2	+0·1	+0·3	+0·6	+1·1	+2·4	**+3·0**	+2·2	+1·3	−1·2	−2·7	**−2·9**	−2·2	−0·8	−0·2	0·0	−0·3	−0·4	−0·3	−0·4	−0·2	+0·1	+0·1
Summer Means ...	11·9	+0·2	+0·3	+0·3	+0·4	+0·4	+0·6	+1·5	+2·4	**+2·8**	+2·2	+1·0	−0·8	−1·9	**−2·5**	−2·3	−1·6	−0·9	−0·4	−0·3	−0·5	−0·6	−0·5	−0·3	−0·2	+0·1

* 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 5.—*Horizontal force at Dehra Dūn in 1930* (determined from 5 selected quiet days in each month).

Month	Monthly mean *	Hourly mean *minus* monthly 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 ...	32 952	−6	**−6**	−4	−4	−5	−5	−1	+2	+ 3	− 1	− 5	− 4	+ 7	**+12**	+ 8	+ 5	+3	+ 2	+4	−1	−2	− 4	−3	−1	+4
February ...	958	−6	**−9**	−7	−5	−5	−3	−1	+2	+ 6	+10	+12	+10	+13	**+17**	+10	+ 4	−1	− 3	−4	−5	−7	− 5	−6	−8	−4
March ...	963	−3	−1	+1	+2	0	−1	−1	−5	**− 7**	0	+ 4	+ 9	+15	**+16**	+ 9	+ 4	0	− 2	−7	−4	−6	− 5	−2	−1	+6
October ...	956	−2	−1	0	0	+1	+1	+1	−1	− 4	− 7	− 5	+ 3	+10	**+16**	+11	+ 4	−2	− 7	**−8**	−2	−4	− 4	−2	−2	−2
November ...	976	**−9**	−5	−7	−5	−8	−6	−4	+2	+ 5	+ 9	+12	+13	**+14**	+11	+ 4	+ 1	−1	− 3	−5	−5	−5	− 4	−2	−2	−3
December ...	973	−7	−7	−7	**−8**	−5	−5	−2	0	+ 6	+10	**+12**	+11	+11	+ 9	+ 6	+ 3	+2	0	−4	−4	−4	− 3	−4	−3	−2
Winter Means ...	32 963	**−6**	−5	−4	−3	−4	−3	−1	0	+ 2	+ 4	+ 5	+ 7	+12	**+14**	+ 8	+ 4	0	− 2	−4	−4	−5	− 4	−3	−3	0
April ...	32 954	−4	+5	+3	0	−1	0	0	−5	− 6	− 2	+ 7	+16	**+19**	+16	+16	0	−7	**−12**	−6	−6	−8	−10	−6	−3	−7
May ...	963	−8	−6	−6	−8	−7	−6	−6	−9	**−12**	− 6	− 3	+ 9	+13	**+17**	+14	+ 9	+2	+ 1	0	−1	−2	− 1	+2	+4	+7
June ...	964	**−5**	−5	−3	−3	−5	−2	−2	−3	− 3	− 3	0	+ 2	+ 3	+ 7	**+ 9**	+ 8	+5	− 1	−2	−2	0	0	0	+2	+2
July ...	962	−3	+1	−3	−3	−4	−2	+1	−4	**− 9**	− 7	− 5	0	+13	+12	**+16**	+12	+6	0	−3	−5	−3	− 2	+2	0	−2
August ...	972	−1	−6	**−7**	−4	−4	−3	−3	−5	− 7	− 3	− 1	+ 6	+13	**+15**	+15	+10	+4	− 1	−1	−7	−5	− 6	−2	−1	−3
September ...	957	−3	0	0	−1	+2	+1	+1	−5	−11	−14	**−15**	−13	0	+ 5	**+11**	+ 3	+7	+ 3	+3	+4	+6	+ 3	+3	+4	+5
Summer Means ...	32 962	−4	−2	−3	−3	−3	−2	−2	−5	**− 8**	− 6	− 3	+ 3	+10	+12	**+14**	+ 7	+3	− 2	−2	−3	−2	− 3	0	+1	0

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 6.—*Vertical force at Dehra Dūn in 1930* (determined from 5 selected quiet days in each month).

Month	Monthly mean*	Hourly mean *minus* monthly 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 ...	33 586	0	−1	0	−1	−1	−1	−1	+ 1	+3	+3	− 2	− 6	− 3	− 2	−3	−1	+3	+4	+3	+1	+2	+2	+2	+3	+3
February ...	610	−1	−1	−1	−1	−1	−1	−1	− 1	0	0	− 1	0	− 2	− 3	−2	-1	−1	0	+2	+2	+1	+2	+1	+2	+2
March ...	608	+3	+4	+4	+4	+3	+4	+6	+ 8	+7	+4	− 3	−12	− 9	− 8	−6	−2	+1	0	−1	−1	−1	0	0	0	+1
October ...	659	+4	+2	+3	+2	+1	+1	+2	+ 6	+7	0	− 8	−17	−18	−12	−6	0	+1	+1	0	+4	+5	+4	+5	+5	+6
November ...	664	+1	+2	0	0	0	0	0	+ 1	+3	+3	− 1	− 2	− 2	0	+1	0	0	+1	+1	0	0	+1	+1	0	0
December ...	662	+3	+2	+1	0	0	0	0	− 1	+1	0	− 3	− 4	0	− 1	+1	0	+1	0	−2	−2	−2	−2	−2	−2	−2
Winter Means ...	33 632	+2	+1	+1	+1	0	+1	+1	+ 2	+4	+2	− 3	− 7	− 6	− 4	−3	−1	+1	+1	+1	+1	+1	+1	+1	+1	+2
April ...	33 630	+6	+7	+5	+5	+5	+5	+7	+ 7	+5	−3	−14	−20	−18	−12	−7	−4	0	0	+2	+2	+3	+4	+4	+5	+4
May ...	627	+2	+2	+2	+1	+1	+3	+5	+ 2	−1	−6	−13	−13	− 8	− 4	−1	+2	+3	+4	+2	+1	+2	+3	+3	+5	+5
June ...	630	0	−2	−1	−1	−3	+1	+5	+ 4	−1	−7	−12	−11	− 9	− 7	−3	+2	+4	+5	+5	+4	+4	+4	+4	+5	+4
July ...	626	+3	+2	+1	+2	+2	+3	+7	+ 5	0	−1	− 6	− 9	− 9	− 8	−6	−3	+2	+3	+3	+3	+2	+3	+4	+3	+3
August ...	644	+3	+3	+4	+5	+4	+6	+7	+ 5	+1	−2	− 9	− 8	− 5	− 4	−2	−2	0	−1	−2	−2	−2	−1	0	+1	+2
September ...	625	+7	+7	+7	+7	+6	+6	+8	+10	+7	+2	− 6	− 7	−12	− 7	−6	−4	−1	−1	−2	−2	−2	−3	−2	−3	−4

TABLE 7.—*Dip at Dehra Dūn in 1930* (determined from 5 selected quiet days in each month).

Month	Monthly mean *	Hourly mean *minus* monthly 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 ...	32·8	**+ 0·3**	+0·3	+0·2	+0·1	+0·2	+0·2	0·0	−0·1	0·0	+0·2	+0·1	−0·1	−0·5	**−0·8**	−0·6	−0·3	0·0	+0·1	−0·1	+0·1	+0·1	+0·3	+0·2	+0·2	−0·1
February	33·7	+ 0·3	+0·4	+0·3	+0·2	+0·2	+0·1	0·0	−0·2	−0·3	−0·5	−0·7	−0·5	−0·8	**−1·0**	−0·6	−0·2	0·0	+0·1	+0·3	+0·3	+0·4	+0·3	+0·3	**+0·5**	+0·3
March ...	33·3	+ 0·3	+0·3	+0·2	+0·1	+0·2	+0·3	+0·4	+0·7	**+0·7**	+0·2	−0·4	−1·1	−1·2	**−1·2**	−0·8	−0·3	+0·1	+0·1	+0·3	+0·2	+0·3	+0·3	+0·1	+0·1	−0·2
October ...	36·3	+ 0·3	+0·2	+0·2	+0·1	0·0	0·0	0·0	+0·4	**+0·6**	+0·4	−0·2	−1·0	**−1·5**	−1·5	−0·9	−0·2	+0·1	+0·4	+0·4	+0·3	+0·5	+0·4	+0·4	+0·4	+0·4
November ...	35·5	**+ 0·5**	+0·4	+0·4	+0·3	+0·4	+0·3	+0·2	0·0	−0·1	−0·3	−0·7	−0·8	**−0·8**	−0·5	−0·2	0·0	+0·1	+0·2	+0·3	+0·3	+0·3	+0·2	+0·2	+0·1	+0·2
December ..	35·5	**+ 0·6**	+0·5	+0·4	+0·5	+0·3	+0·3	+0·2	0·0	−0·2	−0·5	**−0·7**	−0·7	−0·5	−0·5	−0·2	−0·1	0·0	0·0	+0·1	+0·1	+0·1	+0·1	+0·1	+0·1	0·0
Winter Means	34·5	**+ 0·4**	+0·4	+0·3	+0·2	+0·2	+0·2	+0·2	+0·2	+0·1	−0·1	−0·4	−0·7	−0·9	**−0·9**	−0·5	−0·2	+0·1	+0·2	+0·2	+0·2	+0·3	+0·3	+0·2	+0·3	+0·1
April ...	34·9	+ 0·5	+0·1	+0·1	+0·3	+0·3	+0·3	+0·4	+0·6	+0·6	0·0	−1·1	−1·8	**−1·9**	−1·4	−1·2	−0·2	+0·4	+0·6	+0·4	+0·4	+0·6	**+0·7**	+0·5	+0·4	+0·6
May ...	34·3	+ 0·5	+0·4	+0·4	+0·5	+0·4	+0·5	+0·5	+0·5	**+0·6**	0·0	−0·5	**−1·2**	−1·1	−1·1	−0·8	−0·4	+0·1	+0·1	+0·1	+0·1	+0·2	+0·2	+0·1	0·0	−0·1
June ...	34·4	+ 0·3	+0·2	+0·1	+0·1	+0·1	+0·2	**+0·4**	+0·4	+0·1	−0·2	−0·6	**−0·7**	−0·6	−0·7	−0·6	−0·4	−0·1	+0·3	+0·4	+0·3	+0·2	+0·2	+0·2	+0·1	+0·1
July ...	34·3	+ 0·3	0·0	+0·2	+0·3	+0·3	+0·2	+0·3	**+0·5**	+0·5	+0·3	−0·1	−0·5	**−1·1**	−1·0	−1·1	−0·8	−0·2	+0·1	+0·3	+0·4	+0·3	+0·2	+0·1	+0·1	+0·2
August ...	34·7	+ 0·2	+0·5	**+0·6**	+0·5	+0·4	+0·5	+0·5	+0·5	+0·4	0·0	−0·4	− 0·7	**−1·0**	−1·0	− 0·9	−0·7	−0·2	0·0	−0·1	+0·3	+0·1	+0·2	+0·1	+0·1	+0·2
September ...	34·5	+ 0·5	+0·3	+0·3	+0·4	+0·2	+0·3	+0·4	+0·8	**+0·9**	+0·8	+0·5	+0·3	−0·6	−0·6	**−0·9**	−0·4	−0·4	−0·2	−0·3	−0·3	−0·4	−0·3	−0·3	−0·4	−0·5
Summer Means ...	34·5	+ 0·4	+0·3	+0·3	+0·4	+0·3	+0·4	+0·4	**+0·6**	+0·5	+0·2	−0·3	−0·7	**−1·0**	−0·9	−0·9	−0·5	0·0	+0·2	+0·2	+0·2	+0·2	+0·2	+0·1	+0·1	+0·1

* 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.

Dun { Lat. 30° 19′ 19″ N.
{ Long. 78 03 19 E.

TABLE 8.—*Classification and dates of Magnetic disturbances at Dehra Dūn in 1930.*

Dates	January	February	March	April	May	June	July	August	September	October	November	December
1930												
1	S	S	M	S	M	M	S	S	M	M	S	—
2	(C)	S	M	S	(C)	S	S	(C)	(C)	S	C	(C)
3	G	M	(C)	(C)	S	M	S	C	S	M	C	VG
4	M	S	S	(C)	S	M	M	(C)	M	G	M	VG
5	M	S	C	S	G	(C)	M	S	S	M	S	S
6	G	S	C	M	G	S	S	G	G	M	(C)	C
7	M	S	C	M	M	S	(C)	G	S	S	C	S
8	S	S	C	G	M	M	(C)	M	S	S	—	(C)
9	(C)	(C)	C	G	M	M	M	M	M	C	—	C
10	C	(C)	(C)	G	S	(C)	G	M	S	S	—	C
11	C	(C)	(C)	M	(C)	(C)	G	M	S	(C)	C	(C)
12	(C)	G	VG	M	M	G	G	M	C	(C)	C	C
13	S	VG	G	S	M	G	M	S	(C)	(C)	(C)	M
14	C	G	G	S	S	M	(C)	S	C	G	M	M
15	S	G	M	(C)	(C)	S	S	M	(C)	M	M	S
16	S	G	M	S	M	VG	S	S	C	(C)	S	S
17	S	M	S	S	G	M	M	S	S	VG	S	C
18	S	M	M	S	M	M	S	(C)	VG	M	C	C
19	S	(C)	M	G	M	S	C	G	G	M	C	M
20	S	S	(C)	G	M	S	C	(C)	(C)	M	(C)	M
21	M	M	S	G	S	S	C	M	M	S	(C)	M
22	S	(C)	M	G	M	S	(C)	M	S	(C)	C	S
23	S	S	M	M	M	(C)	S	M	S	S	(C)	S
24	(C)	S	G	M	(C)	C	(C)	M	S	C	M	S
25	S	M	S	S	S	(C)	G	S	S	M	G	C
26	(C)	S	M	(C)	S	S	G	S	S	G	M	—
27	C	S	M	(S)	(C)	S	M	S	(C)	G	M	—
28	S	M	M	S	C	M	S	C	M	M	C	(C)
29	S	...	M	M	S	M	M	(C)	G	M	S	S
30	M	...	(C)	M	M	M	S	C	M	M	—	S
31	S	...	S	...	M	...	S	C	...	M	...	(C)
C	9	5	10	4	6	6	8	9	8	7	14	12
S	15	12	5	11	8	10	11	9	12	6	5	9
M	5	6	12	8	14	11	7	10	6	13	6	5
G	2	4	3	7	3	2	5	3	3	4	1	...
VG	...	1	1	...	...	1	...	...	1	1	...	2

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

TABLE 9.—*Mean values of the constants of Magnetometer No. 4 in 1930-31.*

Month	Declination constants	H. F. constants				
	Mean magnetic collimation	Distribution factors			Mean values of *m*	
		$P_{1\cdot2}$	$P_{2\cdot3}$	Accepted value of $\log(1+P/r^2+Q/r^4)^{-1}$	Monthly means	Accepted *m*
	′ ″	cm^2	cm^2		C. G. S.	C. G. S.
October ...	− 2 14	7·55	8·18	1·99415 throughout	865·76	865·76
November	− 2 14	7·51	8·48		·94	·94
December	− 2 15	7·57	8·57		·77	·77
January ...	− 2 10	7·46	8·55		·70	·70
February...	− 2 11	7·44	8·70		·65	·65
March ...	− 1 42	7·58	8·75		·70	·70
April ...	...	7·37	8·85		865·72	865·72

TABLE 10.—*Comparison between observatory and field constants.*

	Dehra Dūn *minus* field Oct. 1930	Dehra Dūn *minus* field March 1931	Alībāg *minus* field Jan. 1931
	′	′	′
Declination ...	− 0·3	− 0·4	+ 1·9
Horizontal force	+ 9 γ	+ 8 γ	+ 41 γ
Dip ...	− 3·0	− 4·7	− 2·0

$\gamma = 0\cdot00001$ C. G. S.

TABLE 11.—*The values of Declination reduced to epochs 1909·0, 1920·0 and 1931·0 and the Annual changes for the periods 1902-09, 1909-15, 1915-20 and 1920-31.*

Degree Sheet No.	Station No.	Name of Station	Latitude N.	Longitude E.	Height	Date of observation	Value on date	Value reduced to the epoch 1909·0	Value reduced to the epoch 1920·0	Value reduced to the epoch 1931·0	Annual changes			
											1902-09	1909-15	1915-20	1920-31
			° ′ ″	° ′ ″	feet		° ′	° ′	° ′	° ′	′	′	′	′
34 J	III	Quetta	30 12 21	66 59 55	5500	19 11 30	+2 19·5	+2 58·3	+2 51·0	+2 19·2	+ 1·4	+ ·2	− 1·7	− 2·9
35 P	II	Karāchi	24 49 24	67 2 28	20	27 11 30	+0 59·4	+1 41·7	+1 26·2	+0 59·2	+ 1·0	− ·5	− 2·5	− 2·5
38 N	XXVI	Peshāwar ...	34 0 40	71 33 40	1050	6 11 30	+3 9·3	+3 48·8	+3 29·3	+3 9·1	+ 1·4	− 1·0	− 2·7	− 1·1
38 P	XXVII	Kundiān	32 27 30	71 28 20	650	10 11 30	+2 26·4	+3 27·8	+3 6·6	+2 25·9	+ 1·1	− 1·3	− 2·8	− 3·7
39 O	IV	Bahāwalpur ...	29 24 23	71 40 35	380	15 11 30	+1 50·9	+2 52·6	+2 28·1	+1 50·5	+ ·5	− 1·5	− 3·1	− 3·4
40 A	XXIV	Ruk Junction ...	27 48 23	68 38 20	200	23 11 30	+1 15·3	+2 3·4	+1 46·7	+1 15·0	+ ·8	− ·7	− 2·5	− 2·9
40 G	XXXI	Mīrpur Khās ...	25 31 19	69 1 40	50	30 11 30	+1 4·1	+1 54·2	+1 33·6	+1 3·9	+ ·5	− 1·1	− 2·8	− 2·7
40 O	LXXIII	Bārmer	25 44 35	71 26 40	650	3 12 30	+0 51·1	+1 53·5	+1 25·7	+0 50·9	− ·1	− 1·8	− 3·4	− 3·2
41 G	IX	Porbandar ...	21 37 43	69 36 39	30	27 12 30	+0 15·7	+1 12·9	+0 45·7	+0 15·7	− ·3	− 1·7	− 3·4	− 2·7
43 G	V	Rāwalpindi ...	33 35 25	73 3 6	1700	2 11 30	+2 36·1	+3 41·9	+3 18·0	+2 35·4	+ 1·1	− 1·5	− 3·1	− 3·9
44 H	XXIX	Bīkaner	28 0 40	73 18 50	750	7 12 30	+0 55·7	+2 4·2	+1 33·0	+0 55·5	− ·1	− 2·2	− 3·6	− 3·4
44 I	XXV	Lahore	31 35 50	74 18 50	700	26 10 30	+1 44·8	+2 57·8	+2 28·4	+1 44·1	+ ·4	− 1·9	− 3·6	− 4·0
44 O	XLIII	Sirsa	29 32 10	75 2 40	700	28 2 31	+1 22·3	+2 39·3	+2 3·8	+1 22·9	− ·3	− 2·5	− 4·0	− 3·7
45 H	I	Udaipur	24 34 42	73 42 46	1900	17 12 30	+0 15·4	+1 25·0	+0 49·9	+0 15·3	− ·8	− 2·6	− 3·9	− 3·1
45 J	XXX	Ajmer	26 27 30	74 38 30	1600	13 12 30	+0 46·1	+2 1·2	+1 24·4	+0 45·9	− ·8	− 2·8	− 4·0	− 3·5
46 A	XXXII	Viramgām ...	23 8 10	72 3 30	90	23 12 30	+0 5·3	+1 9·6	+0 37·9	+0 5·2	− ·7	− 2·2	− 3·7	− 3·2
46 C	XXVIII	Sachīn	21 4 40	72 52 40	40	31 12 30	−0 40·9	+0 29·3	−0 7·6	−0 40·9	− 1·2	− 2·8	− 4·0	− 3·0
46 L	XLI	Manmād	20 14 40	74 26 20	1900	26 1 31	−0 11·0	+1 0·1	+0 18·9	−0 10·8	− 1·7	− 3·2	− 4·4	− 2·7

46 N	LVI	Indore	22 42 8	75 52 40	1800	1 2 31	−0 25·2	+0 53·3	+0 11·0	−0 24·9	− 1·7	− 3·3	− 4·5	− 3·3
46 O	XVI	Bhusāwal ...	21 3 40	75 47 0	650	29 1 31	−0 37·4	+0 42·5	−0 0·4	−0 37·1	− 1·9	− 3·4	− 4·6	− 3·4
47 B		ALIBAG OBSY. ...	18 38 17	72 52 26	20	...	...	+1 0·7	+0 20·9	−0 11·3	− 1·7	− 3·1	− 4·3	− 2·9
47 J	XXXIII	Dhond	18 28 0	74 35 10	1690	14 1 31	−0 47·7	+0 29·7	−0 13·7	−0 47·6	− 2·1	− 3·3	− 4·6	− 3·1
53 H	XLII	Delhi	28 40 15	77 13 48	680	3 3 31	+0 51·4	+2 16·2	+1 34·5	+0 52·0	− 1·0	− 3·2	− 4·5	− 3·8
53 J		DEHRA DUN OBSY.	30 19 19	78 3 19	2230	...	...	+2 36·5	+1 54·5	+1 9·5	− ·9	− 3·2	− 4·6	− 4·0
53 O	LVIII	Kāthgodām ...	29 15 19	79 32 50	1680	22 3 31	+0 51·7	+2 22·7	+1 36·0	+0 52·6	− 1·5	− 3·7	− 4·9	− 4·0
54 C	LIV	Bāran	25 5 32	76 30 30	850	21 2 31	+0 6·1	+1 28·2	+0 45·9	+0 6·6	− 1·4	− 3·3	− 4·5	− 3·6
54 E	VI	Bharatpur ...	27 13 53	77 29 24	650	24 2 31	+0 34·8	+2 0·7	+1 17·3	+0 35·3	− 1·3	− 3·4	− 4·6	− 3·8
54 L	LV	Bīna	24 10 50	78 11 0	1350	18 2 31	−0 8·8	+1 17·9	+0 31·7	−0 8·3	− 1·9	− 3·7	− 4·8	− 3·7
55 H	LXIV	Amraoti	20 55 30	77 45 50	1120	3 2 31	−1 5·3	+0 20·3	−0 26·6	−1 5·0	− 2·3	− 3·8	− 4·8	− 3·3
55 M	XVII	Jubbulpore ...	23 9 26	79 57 9	1320	13 2 31	−0 29·5	+1 1·2	+0 11·0	−0 29·1	− 2·4	− 4·2	− 5·1	− 3·7
56 A	XLVII	Parbhani ...	19 15 20	76 46 50	1350	23 1 31	−1 1·6	+0 21·7	−0 25·7	−1 1·4	− 2·4	− 3·8	− 4·9	− 3·2
56 C	XXXIV	Hotgi	17 33 40	76 0 20	1530	18 1 31	−1 4·4	+0 17·7	−0 29·6	−1 4·2	− 2·6	− 3·8	− 4·9	− 3·1
56 K	XV	Secunderābād ...	17 27 44	78 29 37	1760	20 1 31	−1 12·6	+0 15·3	−0 36·7	−1 12·4	− 3·1	− 4·4	− 5·1	− 3·2
56 M	LXII	Chānda	19 57 50	79 17 40	770	6 2 31	−0 55·6	+0 32·7	−0 18·2	−0 55·3	− 2·8	− 4·3	− 5·0	− 3·4
62 H	LII	Katarnian Ghāt ...	28 19 50	81 7 50	600	17 3 31	+0 32·7	+2 7·7	+1 17·6	+0 33·5	− 2·0	− 4·1	− 5·1	− 4·0
63 B	LVII	Cawnpore ...	26 27 0	80 21 0	400	8 3 31	+0 15·0	+1 49·1	+0 59·0	+0 15·7	− 2·1	− 4·1	− 5·1	− 3·9
63 G	XLIX	Mānikpur ...	25 3 10	81 5 20	800	12 3 31	−0 10·4	+1 24·7	+0 32·9	−0 9·7	− 2·4	− 4·3	− 5·2	− 3·9
63 J	X	Fyzābād ...	26 48 5	82 8 5	330	14 3 31	+0 7·5	+1 45·2	+0 52·8	+0 8·3	− 2·5	− 4·4	− 5·2	− 4·0
64 G	LXIII	Raipur	21 15 50	81 38 20	970	8 2 31	−0 49·6	+0 43·2	−0 10·9	−0 49·2	− 3·2	− 4·6	− 5·1	− 3·5

TABLE 12.—*The values of Horizontal Force reduced to epochs 1909·0, 1920·0 and 1931·0 and the Annual changes for the periods 1902-09, 1909-15, 1915-20 and 1920-31.*

Degree Sheet No.	Station No.	Name of Station	Latitude N.	Longitude E.	Height	Date of observation	Value on date	Value reduced to the epoch 1909·0	Value reduced to the epoch 1920·0	Value reduced to the epoch 1931·0	Annual changes 1902-09	Annual changes 1909-15	Annual changes 1915-20	Annual changes 1920-31
			° ′ ″	° ′ ″	*feet*		C. G. S.	C. G. S.	C. G. S.	C. G. S.	γ	γ	γ	γ
34 J	III	Quetta	30 12 21	66 59 55	5500	18 11 30	·31850	·32293	·31865	·31850	−34	−38	−40	− 1
35 P	II	Karāchi	24 49 24	67 2 28	20	26 11 30	·34505	·34554	·34321	·34507	−29	−23	−19	+17
38 N	XXVI	Peshāwar ...	34 0 40	71 33 40	1050	6 11 30	·30201	·30907	·30369	·30199	−41	−48	−50	−15
38 P	XXVII	Kundiān	32 27 30	71 28 20	650	10 11 30	·30411	·31041	·30563	·30409	−38	−43	−44	−14
39 O	IV	Bahāwalpur ...	29 24 23	71 40 35	380	14 11 30	·32767	·33118	·32761	·32767	−31	−32	−33	+ 1
40 A	XXIV	Ruk Junction ...	27 48 23	68 38 20	200	23 11 30	·33261	·33520	·33196	·33262	−31	−29	−30	+ 6
40 G	XXXI	Mīrpur Khās ...	25 31 19	69 1 40	50	30 11 30	·34406	·34483	·34240	·34407	−27	−23	−21	+15
40 O	LXXIII	Barmer	25 44 35	71 26 40	650	3 12 30	·34331	·34412	·34181	·34332	−24	−21	−21	+14
41 G	IX	Porbandar ..	21 37 43	69 36 39	30	27 12 30	·36286	·36102	·35974	·36286	−19	−13	−10	+28
43 G	V	Rāwalpindi ..	33 35 25	73 3 6	1700	2 11 30	·30561	·31206	·30706	·30559	−39	−45	−46	−13
44 H	XXIX	Bīkaner	28 0 40	73 18 50	750	7 12 30	·33697	·33911	·33621	·33697	−27	−25	−28	+ 7
44 I	XXV	Lahore	31 35 50	74 18 50	700	27 10 30	·31637	·32121	·31709	·31636	−33	−37	−38	− 7
44 O	XLIII	Sirsa	29 32 10	75 2 40	700	1 3 31	·33107	·33404	·33081	·33107	−28	−28	−31	+ 2
45 H	I	Udaipur	24 34 42	73 42 46	1900	17 12 30	·35350	·35272	·35131	·35351	−20	−11	−15	+20
45 J	XXX	Ajmer	26 27 30	74 38 30	1600	12 12 30	·34590	·34656	·34444	·34591	−23	−17	−22	+13
46 A	XXXII	Viramgām ...	23 8 10	72 3 30	90	23 12 30	·35810	·35670	·35545	·35811	−18	−10	−13	+24
46 C	XXVIII	Sachīn	21 4 40	72 52 40	40	31 12 30	·36821	·36521	·36501	·36821	−10	0	− 4	+29
46 L	XLI	Manmād	20 14 40	74 26 20	1900	26 1 31	·37244	·36638	·36678	·37240	− 5	+ 5	+ 2	+51

46 N	LVI	Indore	22 42 8	75 52 40	1800	1 2 31	·37012	·36742	·36719	·37010	− 11	+ 2	− 7	+ 26
46 O	XVI	Bhusāwal	21 3 40	75 47 0	650	29 1 31	·37131	·36769	·36805	·37129	− 5	+ 6	0	+ 30
47 B		ALIBAG OBSY.	18 38 17	72 52 26	20	...		·36793	·36857	·37256	− 5	+ 6	+ 6	+ 36
47 J	XXXIII	Dhond	18 28 0	74 35 10	1690	15 1 31	·37581	·37068	·37156	·37579	− 2	+ 8	+ 8	+ 39
53 H	XLII	Delhi	28 40 15	77 13 48	680	4 3 31	·33814	·33994	·33721	·33813	− 24	− 23	− 27	+ 8
53 J		DEHRA DUN OBSY.	30 19 19	78 3 19	2230	..	..	33280	·32954	·32962	− 26	− 28	− 32	+ 2
53 O	LVIII	Kāthgodām	29 15 19	79 32 50	1680	21 3 31	·33608	·33812	·33551	·33607	− 21	− 21	− 27	+ 5
54 C	LIV	Bāran	25 5 32	76 30 30	850	20 2 31	·35334	·35236	·35118	·35331	− 17	− 8	− 14	+ 20
54 E	VI	Bharatpur	27 13 53	77 29 24	650	24 2 31	·34467	·34553	·34341	·34465	− 21	− 17	− 22	+ 11
54 L	LV	Bīna	24 10 50	78 11 0	1350	18 2 31	·35885	·35681	·35629	·35882	− 11	− 2	− 8	+ 23
55 H	LXIV	Amraoti	20 55 30	77 45 50	1120	4 2 31	·37054	·36411	·36480	·37049	− 3	+ 9	+ 3	+ 52
55 M	XVII	Jubbulpore	23 9 26	79 57 9	1320	12 2 31	·36765	·36473	·36480	·36762	− 5	+ 2	− 1	+ 26
56 A	XLVII	Parbhani	19 15 20	76 46 50	1350	23 1 31	·37400	·36891	·36997	·37398	− 1	+ 11	+ 8	+ 36
56 C	XXXIV	Hotgi	17 33 40	76 0 20	1530	17 1 31	·38059	·37461	·37604	·38057	+ 1	+ 13	+ 13	+ 41
56 K	XV	Secunderābād	17 27 44	78 29 37	1760	20 1 31	·38579	·37935	·38128	·38577	+ 5	+ 18	+ 17	+ 41
56 M	LXII	Chānda	19 57 50	79 17 40	770	6 2 31	·37870	·37360	·37483	·37867	+ 1	+ 13	+ 9	+ 35
62 H	LII	Katarnian Ghāt	28 19 50	81 7 50	600	18 3 31	·34417	·34520	·34315	·34415	− 15	− 15	− 23	+ 9
63 B	LVII	Cawnpore	26 27 0	80 21 0	400	8 3 31	·35343	·35317	·35182	·35340	− 13	− 10	− 15	+ 14
63 G	XLIX	Mānikpur	25 3 10	81 5 20	800	12 3 31	·36047	·35874	·35820	·36043	− 7	− 4	− 6	+ 20
63 J	X	Fyzābād	26 48 5	82 8 5	330	15 3 31	·35332	·35290	·35172	·35329	− 9	− 8	− 14	+ 14
64 G	LXIII	Raipur	21 15 50	81 38 20	970	9 2 31	·37589	·37130	·37242	·37586	+ 4	+ 12	+ 8	+ 31

TABLE 13.—*The values of Dip reduced to epochs 1909·0, 1920·0 and 1931·0 and the Annual changes for the periods 1902-09, 1909-15, 1915-20 and 1920-31.*

Degree Sheet No.	Station No.	Name of Station	Latitude N.	Longitude E.	Height	Date of observation	Value on date	Value reduced to the epoch 1909·0	Value reduced to the epoch 1920·0	Value reduced to the epoch 1931·0	Annual changes			
											1902-09	1909-15	1915-20	1920-31
			° ′ ″	° ′ ″	*feet*		° ′	° ′	° ′	° ′	′	′	′	′
34 J	III	Quetta	30 12 21	66 59 55	5500	19 11 30	45 37·0	43 9·6	44 41·1	45 37·6	+ 6·5	+ 9·0	+ 7·5	+ 5·1
35 P	II	Karāchi	24 49 24	67 2 28	20	28 11 30	36 47·0	34 16·6	35 51·3	36 47·5	+ 7·4	+ 9·2	+ 7·9	+ 5·1
38 N	XXVI	Peshāwar	34 0 40	71 33 40	1050	6 11 30	50 59·2	48 48·8	50 10·6	50 59·9	+ 5·7	+ 7·8	+ 7·0	+ 4·4
38 P	XXVII	Kundiān	32 27 30	71 28 20	650	11 11 30	49 44·2	47 33·9	48 57·4	49 44·8	+ 6·0	+ 8·0	+ 7·1	+ 4·3
39 O	IV	Bahāwalpur	29 24 23	71 40 35	380	15 11 30	44 48·2	42 13·6	43 38·9	44 49·0	+ 6·3	+ 8·3	+ 7·1	+ 6·3
40 A	XXIV	Ruk Junction	27 48 23	68 38 20	200	24 11 30	41 52·0	39 25·0	40 56·5	41 52·5	+ 6·8	+ 9·0	+ 7·5	+ 5·1
40 G	XXXI	Mīrpur Khās	25 31 19	69 1 40	50	1 12 30	37 55·3	35 33·8	37 4·7	37 55·7	+ 7·0	+ 8·9	+ 7·5	+ 4·6
40 O	LXXIII	Barmer	25 44 35	71 26 40	650	4 12 30	38 30·3	36 16·5	37 42·9	38 30·6	+ 6·7	+ 8·4	+ 7·2	+ 4·3
41 G	IX	Porbandar	21 37 43	69 36 39	30	28 12 30	31 2·9	28 41·9	30 15·5	31 2·9	+ 7·4	+ 9·1	+ 7·8	+ 4·3
43 G	V	Rāwalpindi	33 35 25	73 3 6	1700	3 11 30	50 25·2	48 18·3	49 39·0	50 25·9	+ 5·6	+ 7·7	+ 6·9	+ 4·2
44 H	XXIX	Bīkaner	28 0 40	73 18 50	750	8 12 30	42 12·1	39 59·6	41 22·1	42 12·4	+ 6·3	+ 8·0	+ 6·9	+ 4·5
44 I	XXV	Lahore	31 35 50	74 18 50	700	27 10 30	48 1·7	45 55·2	47 15·9	48 2·5	+ 5·8	+ 7·7	+ 6·9	+ 4·2
44 O	XLIII	Sirsa	29 32 10	75 2 40	700	28 2 31	44 29·9	42 25·0	43 45·2	44 29·3	+ 5·9	+ 7·7	+ 6·8	+ 4·1
45 H	I	Udaipur	24 34 42	73 42 46	1900	19 12 30	36 4·6	33 55·0	35 17·0	36 4·7	+ 6·6	+ 8·0	+ 6·8	+ 4·3
45 J	XXX	Ajmer	26 27 30	74 38 30	1600	13 12 30	39 21·6	37 18·0	38 37·2	39 21·8	+ 6·3	+ 7·7	+ 6·6	+ 4·0
46 A	XXXII	Viramgām	23 8 10	72 3 30	90	24 12 30	33 29·8	31 14·9	32 41·9	33 29 9	+ 6·9	+ 8·5	+ 7·2	+ 4·4
46 C	XXVIII	Sachīn	21 4 40	72 52 40	40	1 1 31	29 32·1	27 22·4	28 48·4	29 32·1	+ 6·9	+ 8·5	+ 7·0	+ 4·0
46 L	XLI	Manmād	20 14 40	74 26 20	1900	26 1 31	27 23·0	25 21·7	26 42·7	27 22·8	+ 6·6	+ 8·0	+ 6·6	+ 3·7

46 N	LVI	Indore	22 42 8	75 52 40	1800	1 2 31	32 33·0	30 40·6	31 57·1	32 32·7	+ 6·3	+ 7·5	+ 6·3	+ 3·3
46 O	XVI	Bhusāwal .	21 3 40	75 47 0	650	29 1 31	29 5·8	27 10·0	28 27·1	29 5·5	+ 6·4	+ 7·6	+ 6·3	+ 3·5
47 B		ALIBAG OBSY. ...	18 38 17	72 52 26	20	...	..	23 26·0	24 53·3	25 33·0	+ 7·0	+ 8·6	+ 7·1	+ 3·6
47 J	XXXIII	Dhond	18 28 0	74 35 10	1690	15 1 31	24 9·0	22 8·3	23 28·3	24 8·8	+ 6·6	+ 8·0	+ 6·4	+ 3·7
53 H	XLII	Delhi	28 40 15	77 13 48	680	3 3 31	43 4·8	41 6·6	42 22·4	43 4·1	+ 5·7	+ 7·3	+ 6·4	+ 3·8
53 J		DEHRA DUN OBSY.	30 19 19	78 3 19	2230	...	..	43 44·1	44 59·1	45 39·1	+ 5·4	+ 7·2	+ 6·4	+ 3·6
53 O	LVIII	Kāthgodām ...	29 15 19	79 32 50	1680	22 3 31	43 55·6	42 7·4	43 18·2	43 54·8	+ 5·3	+ 6·8	+ 6·0	+ 3·4
54 C	LIV	Bāran ...	25 5 32	76 30 30	850	21 2 31	37 13·9	35 15·9	36 31·8	37 13·4	+ 6·1	+ 7·4	+ 6·3	+ 3·8
54 E	VI	Bharatpur .	27 13 53	77 29 24	650	24 2 31	40 47·2	38 48·9	40 3·1	40 46·6	+ 5·8	+ 7·2	+ 6·2	+ 4·0
54 L	LV	Bīna	24 10 50	78 11 0	1350	18 2 31	34 50·0	33 2·6	34 14·6	34 49·6	+ 5·8	+ 7·0	+ 6·0	+ 3·2
55 H	LXIV	Amraoti ..	20 55 30	77 45 50	1120	4 2 31	28 26·5	27 27·6	28 39·1	28 26·6	+ 6·0	+ 7·0	+ 5·9	— 1·1
55 M	XVII	Jubbulpore .	23 9 26	79 57 9	1320	13 2 31	32 50·1	31 8·6	32 15·0	32 49·7	+ 5·5	+ 6·4	+ 5·6	+ 3·2
56 A	XLVII	Parbhani ...	19 15 20	76 46 50	1350	23 1 31	26 6·9	24 20·7	25 34·4	26 6·7	+ 6·2	+ 7·2	+ 6·1	+ 3·0
56 C	XXXIV	Hotgi ..	17 33 40	76 0 20	1530	18 1 31	22 1·1	20 18·3	21 33·3	22 1·0	+ 6·3	+ 7·5	+ 6·0	+ 2·5
56 K	XV	Secunderābād ..	17 27 44	78 29 37	1760	20 1 31	21 57·7	20 31·4	21 36·9	21 57·6	+ 5·7	+ 6·5	+ 5·3	+ 1·9
56 M	LXII	Chānda	19 57 50	79 17 40	770	5 2 31	26 38·2	25 4·2	26 9·6	26 38·0	+ 5·6	+ 6·4	+ 5·4	+ 2·6
62 H	LII	Katarnian Ghāt ...	28 19 50	81 7 50	600	18 3 31	42 16·2	40 34·4	41 40·8	42 15·5	+ 5·1	+ 6·4	+ 5·6	+ 3·2
63 B	LVII	Cawnpore ...	26 27 0	80 21 0	400	9 3 31	39 6·1	37 25·2	38 32·2	39 5·5	+ 5·3	+ 6·5	+ 5·6	+ 3·1
63 G	XLIX	Mānikpur .	25 3 10	81 5 20	800	12 3 31	36 37·9	34 57·8	36 3·1	36 37·3	+ 5·2	+ 6·3	+ 5·5	+ 3·2
63 J	X	Fyzābād	26 48 5	82 8 5	330	14 3 31	39 39·8	38 4·6	39 8·3	39 39·2	+ 5·0	+ 6·2	+ 5·3	− 2·9
64 G	LXIII	Raipur	21 15 50	81 38 20	970	9 2 31	29 24·0	27 56·6	28 56·9	29 23·7	+ 5·0	+ 5·8	+ 5·1	+ 2·5

TABLE 14.—*The values of the Total Force and its components reduced to epochs 1909·0, 1920·0 and 1931·0.*

Degree sheet No.	Station No.	Name of Station	Latitude N.	Longitude E.	1909·0				1920·0				1931·0			
					Total Force F	COMPONENTS			Total Force F	COMPONENTS			Total Force F	COMPONENTS		
						North X	E. or W. Y	Vertical Z		North X	E. or W. Y	Vertical Z		North X	E. or W. Y	Vertical Z
			° ′ ″	° ′ ″	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.	C.G.S.
34 J	III	Quetta	30 12 21	66 59 55	·44271	·32250	+ ·01674	+ ·30283	·44818	·31825	+ ·01584	+ ·31516	·45544	·31824	+ ·01287	+ ·32562
35 P	II	Karāchi ...	24 49 24	67 2 28	·41817	·34539	+ ·01022	+ ·23550	·42346	·34310	+ ·00860	+ ·24803	·43090	·34502	+ ·00592	+ ·25815
38 N	XXVI	Peshāwar ...	34 0 40	71 33 40	·46934	·30839	+ ·02056	+ ·35322	·47421	·30312	+ ·01848	+ ·36420	·47984	·30153	+ ·01659	+ ·37292
38 P	XXVII	Kundiān ...	32 27 30	71 28 20	·46004	·30985	+ ·01875	+ ·33953	·46546	·30518	+ ·01658	+ ·35105	·47060	·30382	+ ·01291	+ ·35920
39 O	IV	Bahāwalpur ...	29 24 23	71 40 35	·44724	·33076	+ ·01662	+ ·30057	·45276	·32731	+ ·01411	+ ·31251	·46192	·32750	+ ·01058	+ ·32558
40 A	XXIV	Ruk Junction ...	27 48 23	68 38 20	·43389	·33498	+ ·01203	+ ·27550	·43947	·33180	+ ·01030	+ ·28798	·44671	·33254	+ ·00726	+ ·29827
40 G	XXXI	Mīrpur Khās ...	25 31 19	69 1 40	·42390	·34464	+ ·01145	+ ·24654	·42917	·34227	+ ·00932	+ ·25875	·43620	·34401	+ ·00641	+ ·26818
40 O	LXIII	Barmer ...	25 44 35	71 26 40	·42685	·34393	+ ·01136	+ ·25255	·43209	·34170	+ ·00852	+ ·26432	·43875	·34328	+ ·00509	+ ·27325
41 G	IX	Porbandar ...	21 37 43	69 36 39	·41158	·36094	+ ·00766	+ ·19764	·41649	·35971	+ ·00478	+ ·20986	·42354	·36286	+ ·00169	+ ·21846
43 G	V	Rāwalpindi ...	33 35 25	73 3 6	·46915	·31141	+ ·02013	+ ·35031	·47425	·30655	+ ·01768	+ ·36143	·47973	·30528	+ ·01377	+ ·36984
44 H	XXIX	Bīkaner ...	28 0 40	73 18 50	·44263	·33889	+ ·01225	+ ·28448	·44800	·33609	+ ·00909	+ ·29608	·45491	·33692	+ ·00549	+ ·30555
44 I	XXV	Lahore	31 35 50	74 18 50	·46173	·32078	+ ·01661	+ ·33170	·46726	·31680	+ ·01368	+ ·34320	·47317	·31621	+ ·00957	+ ·35197
44 O	XLIII	Sirsa	29 32 10	75 2 40	·45247	·33368	+ ·01547	+ ·30520	·45797	·33060	+ ·01191	+ ·31672	·46408	·33097	+ ·00799	+ ·32515
45 H	I	Udaipur ..	24 34 42	73 42 46	·42504	·35261	+ ·00872	+ ·23716	·43037	·35127	+ ·00510	+ ·24859	·43739	·35351	+ ·00154	+ ·25762
45 J	XXX	Ajmer ..	26 27 30	74 38 30	·43567	·34635	+ ·01222	+ ·26401	·44085	34433	+ ·00846	+ ·27516	·44740	·34588	+ ·00463	+ ·28380
46 A	XXXII	Viramgām ...	23 8 10	72 3 30	·41722	·35662	+ ·00722	+ ·21644	·42239	·35543	+ ·00392	+ ·22818	·42944	·35812	+ ·00052	+ ·23703
46 C	XXVIII	Sachin ...	21 4 40	72 52 40	·41125	·36519	+ ·00311	+ ·18909	·41655	·36501	− ·00081	+ ·20072	·42320	·36819	− ·00439	+ ·20861
46 L	XLI	Manmād ...	20 14 40	74 26 20	·40545	·36632	+ ·00640	+ ·17367	·41060	·36678	+ ·00202	+ ·18457	·41938	·37240	− ·00119	+ ·19290

46 N	LVI	Indore	22 42 8	75 52 40	·42721	·36738	+ ·00570	+ ·21796	·43275	·36719	+ ·00117	+ ·22901	·43905	·37009	— ·00269	+ ·23623
46 O	XVI	Bhusāwal ...	21 3 40	75 47 0	·41328	·36766	+ ·00455	+ ·18869	·41861	·36805	— ·00004	+ ·19943	·42489	·37126	— ·00400	+ ·20665
47 B		ALIBAG OBSY. ...	18 38 17	72 52 26	·40079	·36768	+ ·00649	+ ·15939	·40655	36878	+ ·00224	+ ·17110	·41294	·37257	— ·00119	+ ·17810
47 J	XXXIII	Dhond	18 28 0	74 35 10	·40018	·37066	+ ·00320	+ ·15081	·40507	·37156	— ·00148	+ ·16134	·41183	·37576	— ·00525	+ ·16850
53 H	XLII	Delhi	28 40 15	77 13 48	·45118	·33967	+ ·01346	+ ·29665	·45645	·33709	+ ·00927	+ ·30762	·49254	·33809	+ ·00511	+ ·31605
53 J		DEHRA DUN OBSY.	30 19 19	78 3 19	·46026	·33221	+ ·01513	+ ·31819	·46618	·32954	+ ·01098	+ ·32955	·47154	·32955	+ ·00671	+ ·33718
53 O	LVIII	Kāthgodām ...	29 15 19	79 32 50	·45587	·33783	+ ·01403	+ ·30577	·46103	·33538	+ ·00937	+ ·31621	·46651	·33603	+ ·00518	+ ·32360
54 C	LIV	Bāran	25 5 32	76 30 30	·43155	·35225	+ ·00904	+ ·24916	·43704	·35115	+ ·00469	+ ·26014	·44370	·35331	+ ·00719	+ ·26834
54 E	VI	Bharatpur ...	27 13 53	77 29 24	·44347	·34532	+ ·01213	+ ·27796	·44863	·34332	+ ·00772	+ ·28868	·45512	·34464	+ ·00351	+ ·29732
54 L	LV	Bina	24 10 50	78 11 0	·42567	·35672	+ ·00808	+ ·23210	·43100	·35627	+ ·00329	+ ·24253	·43712	·35882	— ·00835	+ ·24970
55 H	LXIV	Amraoti ..	20 55 30	77 45 50	·41035	·36410	+ ·00215	+ ·18922	·41570	·36479	— ·00282	+ ·19932	·42136	·37042	— ·00700	+ ·20074
55 M	XVII	Jubbulpore ...	23 9 26	79 57 9	·42615	·36467	+ ·00649	+ ·22039	·43134	·36480	+ ·00117	+ ·23017	·43749	·36760	— ·00310	+ ·23722
56 A	XLVII	Parbhani ...	19 15 20	76 46 50	·40491	·36890	+ ·00233	+ ·16692	·41016	·36996	— ·00277	+ ·17705	·41649	·37392	— ·00664	+ ·18334
56 C	XXXIV	Hotgi	17 33 40	76 0 20	·39943	·37460	+ ·00193	+ ·13861	·40432	·37602	— ·00324	+ ·14854	·41051	·38050	— ·00708	+ ·15389
56 K	XV	Secunderābād ...	17 27 44	78 29 37	·40506	·37935	+ ·00169	+ ·14201	·41012	·38126	— ·00407	+ ·15107	·41595	·38568	— ·00808	+ ·15560
56 M	LXII	Chānda ...	19 57 50	79 17 40	·41247	·37359	+ ·00355	+ ·17477	·41760	·37482	— ·00198	+ ·18411	·42361	·37862	— ·00606	+ ·18990
62 H	LII	Katarnian Ghāt ...	28 19 50	81 7 50	·45446	·34496	+ ·01282	+ ·29559	·45945	·34306	+ ·00775	+ ·30552	·46500	·34414	+ ·00340	+ ·31279
63 B	LVII	Cawnpore ...	26 27 0	80 21 0	·44467	·35299	+ ·01121	+ ·27021	·44978	·35177	+ ·00604	+ ·28022	·45533	·35340	+ ·00164	+ ·28270
63 G	XLIX	Manikpur	25 3 10	81 5 20	·43775	·35863	+ ·00884	+ ·25085	·44305	·35819	+ ·00343	+ ·26074	·44909	·36043	— ·00105	+ ·26784
63 J	X	Fyzābād ...	26 48 5	82 8 5	·44831	·35274	+ ·01080	+ ·27648	·45347	·35168	+ ·00540	+ ·28623	·45886	·35329	+ ·00082	+ ·29279
64 G	LXIII	Raipur ...	21 15 50	81 38 20	·42030	·37127	+ ·00467	+ ·19695	·42560	·37242	— ·00108	+ ·20600	·43140	·37583	— ·00536	+ ·21178

NOTE :—Y is + or — according as Declination is East or West. Z is + or — according as Dip is towards the North or South.

TABLE 15.—*Instrumental constants.*

Year	MAGNETOMETER No. 17			Year	MAGNETOMETER No. 5		
	Accepted log $\pi^2 K$	Observed log $(1+P/r^2+Q/r^4)^{-1}$*	m		Accepted log $\pi^2 K$	Observed log $(1+P/r^2+Q/r^4)^{-1}$†	m
			C. G. S.				C. G. S.
1920	3·414 64	...	806·69				
1921	62	...	807·02				
1922	59	$\bar{1}$·99 436	806·77				
1923	60	393	·77				
1924	58	420	·94	1924	3·377 60	$\bar{1}$·99 288	942·46
1925	57	455	·82	1925	60	287	941·99
1926	56	423	806·95	1926	58	290	·70
1927	55	416	807·10	1927	56	303	·36
1928	54	414	·02	1928	54	295	941·15
1929	53	415	·04	1929	52	290	940·70
1930	3·414 53	$\bar{1}$·99 393	807·06	1930	3·377 50	$\bar{1}$·99 301	{ 940·09‡ { 938·10

* $\bar{1}$·99 415 accepted throughout.

† $\bar{1}$·99 292 accepted throughout.

‡ Up to 6th February.

TABLE 16.—*Annual mean values of $H-32{,}000\gamma$ and discordance between No. 17 & No. 5 Magnetometers.*

Year	No. 5	H_1		H_2		H_3	
		No. 17	No. 5 – No. 17	No. 17	No. 5 – No. 17	No. 17	No. 5 – No. 17
1924	959	951	+ 8	951	+ 8	955	+ 4
1925	953	943	+ 10	942	+ 11	951	+ 2
1926	939	928	+ 11	928	+ 11	931	+ 8
1927	949	936	+ 13	936	+ 13	933	+ 16
1928	948	939	+ 9	941	+ 7	941	+ 7
1929	955	946	+ 9	946	+ 9	945	+ 10
1930	979	963	+ 16	962	+ 17	960	+ 19
Range of variation.			8		10		17

TABLE 17.—*Revised values of m of Magnetometer No. 17.*

Month	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
	C. G. S.	C. G. S.	C. G. S.	C. G. S.	C. G. S.	C. G. S.	C G S.	C. G S.	C. G. S.	C. G. S.	C. G. S.
January ...	806·60	806·90	806·85	806·55	806·84	806·61	806·78	806·90	806·96	806·88	806·87
February ...	·65	806·91	·99	·47	806·88	·86	·84	806·98	806·92	807·02	806·97
March ...	·66	807·07	806·96	·57	807·01	806·91	·83	807·05	807·08	·07	807·17
April ..	·74	·09	807·23	·88	·05	807·05	806·96	·18	·11	·07	·09
May ...	·73	·24	807·07	·88	·07	806·92	807·06	·19	·22	·12	·16
June ...	·70	·19	806·65	·84	807·27	·74	807·24	·33	807·09	·03	807·28
July ...	·56	807·06	·66	·73	806·89	·69	806·86	·17	806·94	807·06	806·97
August ...	·54	806·98	·53	·85	·93	·85	806·94	·04	807·04	*	807·05
September ...	·53	·95	·50	·82	·96	·90	807·04	·09	·02	*	·05
October ...	·79	·94	·42	·92	·87	·77	806·99	·15	807·02	807·18	·07
November ...	·88	·99	·64	·82	·71	·76	·89	·03	806·91	807·00	807·10
December ...	806·84	806·96	806·68	806·86	806·74	806·77	806·97	807·04	806·89	806·96	806·99
Means ...	806·69	807·02	806·77	806·77	806·94	806·82	806·95	807·10	807·02	807·04	807·06

* Magnetometer No. 17 was sent to M. I. O. for repairs.

TABLE 18.—*Monthly mean values of $H - 32{,}000\gamma$. Magnetometer No. 17.*

H_1 results from acceptance of monthly mean values of m.
H_2 results from acceptance of annual mean values of m.
H_3 results from acceptance of smoothed values of m. See Plate XXIII

Month	1920			1921			1922			1923			1924		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	
January	980	982	999	963	968	970	938	939	951	936	944	955	939	943	9
February	980	981	998	967	971	973	938	932	944	933	944	955	942	944	9
March	969	970	987	974	972	974	943	931	943	930	935	946	952	951	9
April	965	965	982	973	970	972	952	931	943	935	928	939	958	953	9
May	977	976	993	956	947	949	963	937	949	942	937	948	959	953	9
June	987	988	1005	963	956	958	949	944	956	941	933	944	960	946	9
July	982	987	1004	968	966	968	937	936	948	941	942	953	956	958	9
August	973	979	996	953	955	957	929	933	945	952	945	956	957	959	9
September	955	961	978	950	953	955	927	928	940	953	946	957	943	942	9
October	956	952	969	949	952	954	918	930	942	941	932	943	951	953	9
November	958	949	966	953	954	956	931	936	948	947	945	956	944	953	9
December	962	956	973	949	951	953	929	936	948	947	945	956	947	955	9
Means	970	971	988	960	960	962	938	934	946	942	940	951	951	951	9

Month	1925			1926			1927			1928			1929			1930	
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
January	941	949	958	920	927	930	923	931	928	965	968	968	941	941	940	952	959
February	947	945	954	913	917	920	938	943	940	942	947	947	961	953	952	958	961
March	949	945	954	914	919	922	933	935	932	948	944	944	945	935	934	963	957
April	960	950	959	922	921	924	934	931	928	945	944	944	951	948	947	954	952
May	955	951	960	936	931	934	938	935	932	959	952	952	953	947	946	963	959
June	940	943	952	940	928	931	957	947	944	939	939	339	949	959	958	964	955
July	939	944	953	934	938	941	950	947	944	927	929	929	943	952	951	962	965
August	944	942	951	941	941	944	931	934	931	932	929	929	...	..	...	972	972
September	934	931	940	937	933	936	934	935	932	929	929	929	...	...	...	957	957
October	934	936	945	919	917	920	920	918	915	914	938	938	940	940	939	956	955
November	935	938	947	927	929	932	936	939	936	929	933	933	937	945	944	976	974
December	938	941	950	933	932	935	933	936	933	937	942	942	935	944	943	973	975
Means	943	942	951	928	928	931	936	936	933	939	941	941	946	946	945	963	962

CHAPTER IX

THE LAY-OUT OF GEODETIC TRIANGULATION,* AND THE INTERVALS BETWEEN BASE-LINES AND LAPLACE POINTS

BY J. DE GRAAFF HUNTER, SC.D.

The Lay-out of Geodetic Triangulation

1. Generally a series of geodetic triangulation is composed of chains of figures of the same type—(*a*) single triangles, (*b*) braced quadrilaterals, (*c*) hexagons,—with occasional odd figures where the land configuration dictates their necessity. Thus (*a*) may contain occasional (*b*) and vice versa; and on occasion when the diagonals of (*b*) offer difficulties another type (*d*)—centred quadrilaterals—may be introduced.

The type (*c*) may be very good and has the advantage of covering a wider region and fixing more precise positions than either (*a*) or (*b*); but this is offset by the additional labour and slowness of progress. Ordinarily the function of a geodetic series is to carry accuracy of relative position in one direction with small accumulation of error, and additional local positions may more economically be provided by the subsequent minor triangulation, which in any case is called for when mapping is undertaken.

Accordingly we may consider types (*a*) and (*b*) as of paramount importance; while (*d*) is of occasional importance and (*c*) will only rarely warrant consideration.

2. The lay-out of whatever type may be decided on is of fundamental importance. The reconnaissance officer has a very responsible task in choosing figures which should balance the qualities of great "strength" with economy of labour for their observation. Accordingly he should have the clearest possible perception of what shape of figure is best and how far this optimum form should be departed from to meet economic conditions. He should know to what degree the subsequent errors of observation may be corrected by introduction of additional base-lines and Laplace points; and again must balance up the economics of these, so that for any postulated degree of accuracy the whole process—triangulation, base-lines and Laplace points—may cost as little as possible and be capable of completion when due. No subsequent efforts of the observer occupying the stations can compensate for ill-laid-out figures.

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* Paper read before the Conference of Empire Surveyors, London 1931.

3. It is proper then to investigate the conditions which govern the strength and performance of figures of various shapes. Ordinarily there is no reason to anticipate that the precision of the subsequent measurements of the several angles will vary except by chance—though in special cases the observer may properly be told to concentrate more than normal observation effort; and so in the first place it is sufficient to consider all angles as of unit weight.

Our first desideratum then is to ascertain the strength of all likely figures as regards log relative scale and relative azimuth of sides of exit and entrance, taking all angles or all directions as of the same weight. In the present paper this has not been carried further than for the cases of single triangles and braced quadrilaterals.

4. We are concerned with two forms of strength of figures, (*a*) as regards scale, (*b*) as regards azimuth. A peculiarity of triangulation is that any error of scale or azimuth is passed on to all the following figures.

Denote by $w_F = 1/u_F$ the strength of log [(side of exit)/(side of entry)], and by ${}_a w_F = 1/{}_a u_F$ the strength of relative azimuth of side of exit to side of entry.

5. I use the words "weight" and "strength" as equivalent, and in my own mind I always think of the strength of a figure. The weight of a function F of the angles is

$$\frac{1}{f^2} \sum_1^n wv^2,$$

where $v_1, \ldots v_n$ are the changes in the n observed angles which cause the change f in F with the least effort. If the angles are represented mechanically and their changes controlled by elastic springs, then Σwv^2 is also proportional to the work done in effecting the change: and the principle of least work shows that such a mechanical arrangement would yield in the "most probable" way. Accordingly we can always replace "minimum square errors" by "work done". An instrument giving effect to this principle is exhibited,* with which it is hoped to solve our problems rapidly.

6. There is little difficulty in writing down an expression for u_F or ${}_a u_F$ in terms of functions of the angles. If there are n observed angles related by r conditions, then u_F is expressible as Δ'/Δ where Δ is a determinant of r rows and Δ' is formed by "bordering" it by one row and column. These determinants are not easy to see through, even for the case of the braced quadrilateral. Simpler results can be obtained by the use of suitable linear functions of the angles, chosen to avoid the entry of so many equations of condition.

7. Two cases arise according to the method in which the angles are to be measured. Some geodesists have advocated the independent measure of each angle; while the more usual (and I think

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* Now at Dehra Dūn.

better) practice is to measure a round of angles as a whole. The former method leads to an independent weight for each single angle, and a reduced weight for a compound angle. The latter method of measuring direction is more economic but leads to the weights of the angles being not independent; however compound angles and single angles are of much the same weight—unless indeed one or more of the directions is shaky, maybe as a result of lateral refraction.

From the point of view of computing the strength of the figure, it is much simpler to have independent weights for each angle. If these are all unity the resulting strength is roughly three-quarters* of that arising when all the directions are measured with weight 2†, if the figure is not too irregular—the improvement due to the direction method resulting from the improved weight of the compound angles.

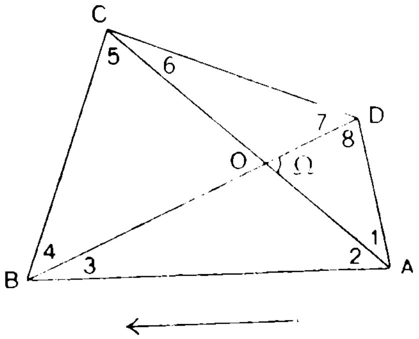
To be strictly precise in the case of the direction method if all the angles at a station are measured in a round, they are all interdependent; and so one figure ought to be considered simultaneously with the next and so on—meaning that *all* figures should be treated simultaneously, which is obviously practically impossible. We must ignore this and consider only those angles at a station which relate to one figure as measured in a round.

8. I have derived some general formulæ, but will refer only to some of the simpler ones. Consider a quadrilateral ABCD of which AB and CD are flank sides and whose diagonals meet in O. Denote the cotangents of the angles at A by c_1, c_2; at B by c_3, c_4 etc. The eight single angles of the figure, beginning with C$\hat{\text{A}}$B may be represented by

$$\tfrac{1}{2}\Omega \pm X, \quad \frac{\pi}{2} - \tfrac{1}{2}\Omega \pm Y, \quad \tfrac{1}{2}\Omega \pm Z, \quad \frac{\pi}{2} - \tfrac{1}{2}\Omega \pm P,$$

Ω being the angle DOA between the diagonals.

$$\text{Let } A = c_2 + c_3,\ B = c_4 + c_5,\ C = c_6 + c_7,\ D = c_8 + c_1;$$
$$A' = c_2 - c_3,\ B' = c_4 - c_5,\ C' = c_6 - c_7,\ D' = c_8 - c_1.$$
$$\text{Also let } e = \tfrac{1}{2}\ (c_2 - c_3 + c_5 - c_8),\ E = e + e';$$
$$e' = \tfrac{1}{2}\ (c_6 - c_7 + c_1 - c_4),\ E' = e - e'.$$



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[*] This is true as regards scale strength; I have not actually considered the case of azimuth strength.

[†] The weight of any angle between two directions of weight 2 is unity.

On the assumption that the angles 1 to 8 are measured independently with equal weights, let u_F be the inverse weight of log (CB/AD), and ${}_a u_F$ of azimuth of BC relative to AD. Let u_{Fl} and ${}_a u_{Fl}$ be similar quantities for the case when directions have been observed by rounds of angles at A, B, C, D. For a rectangular figure $X = Y = Z = P = 0$. Let us call a figure for which none of these quantities exceed 15°, a "quasi-rectangular figure"; and if they do not exceed 5° a "good quasi-rectangular figure".

For a good quasi-rectangular figure $\frac{3}{4}u_F = u_{Fl}$ (nearly). ... (1)

9. When the figure is cyclic, $A = C$, $B = D$, $A' = -C'$, $B' = -D'$, $e = -e'$ and the formulæ are much simplified. There is no other essential merit in the cyclic property; in fact for azimuth

$$ {}_a u_F = 1 - \frac{\frac{1}{2}(B-D)^2}{A^2 + B^2 + C^2 + D^2 + E^2}, \qquad \text{(2)} $$

which is greatest, i.e., worst, when the quadrilateral is cyclic. The variation from this maximum value of unity is clearly small unless the quadrilateral is very irregular.

For *any* cyclic quadrilateral, ${}_a u_F = 1$;
so clearly in the interests of azimuth alone elongated figures are to be preferred.

10. For any quadrilateral,

$$ u_F = \frac{LL' - K^2}{L + L' + 2K} = \frac{1}{4}\left[L + L' - 2K - \frac{(L-L')^2}{L + L' + 2K}\right], \quad \text{(3)} $$

where

$$ \begin{aligned} 2L &= A^2 + c_5^2 + c_8^2 + e^2, \\ 2L' &= C^2 + c_1^2 + c_4^2 + e'^2, \\ 2K &= c_4 c_5 + c_1 c_8 + ee', \end{aligned} $$

and

$$ 2(L + L' + 2K) = A^2 + B^2 + C^2 + D^2 + E^2. $$

This is not difficult to compute, but would be a nuisance to an officer in the field; though on occasion it should be faced.

If however the quadrilateral be cyclic,

$$ u_F = \frac{A^2}{4}\left\{1 + \frac{1}{2}\left(\frac{A'}{A}\right)^2 + \frac{B'^2}{A^2 + B^2}\right\} \qquad \text{(4)} $$

Now it will never happen that the quadrilateral is exactly cyclic; but this equation gives a good idea of what departure from regularity amounts to. From it we can say that for a good quasi-rectangular figure the value of u_F will not be more than 10% greater than for a perfect rectangle. So long as the X, Y, Z, P can be kept down to 5° there is no need to worry; and even 10° would not be serious.

11. For a good quasi-rectangular figure we may write

$$ u_F = \cot^2 \tfrac{1}{2}\Omega, \qquad \text{(5)} $$

with accuracy to 10% or less if Ω is not less than 60°. This shows that for scale error a squat figure is desirable.

12. In the case of a triangle it is easy to show that with unit weight of all angles

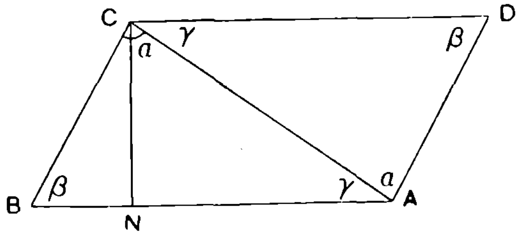
$$u_F = \tfrac{2}{3}\ (c_\alpha^2 + c_\alpha c_\beta + c_\beta^2),$$

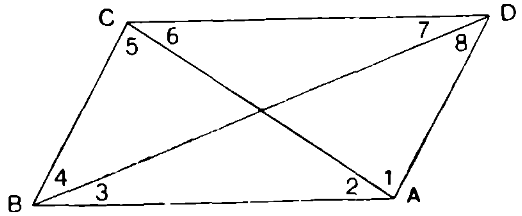
and
$$ {}_\alpha u_F = \tfrac{2}{3}.$$

Consider a pair of such triangles which form a parallelogram. This may be compared with the braced parallelogram for which

$$u_F = \tfrac{1}{4}A^2[1 + (A'/A)^2].$$

On investigation we find that the pair of triangles has a greater strength as regards scale than the similar braced figure when BN is greater than $\frac{1}{4}$ BA. This is because an important angle, when measured as two component angles, has less weight than when measured singly.





I am not convinced of the wisdom under all conditions of the general principle which some have laid down, that geodetic series should always have at least two alternative chains of simple triangles. If one can trust the good faith of the observer, and avoid rays badly affected by lateral refraction, there is much to be said for series of simple triangles, which involve less observation and demand less of the reconnaissance officer.

13. Reverting to the braced quadrilateral, let us now consider the question of *progress* made by the figure. Ground must be covered, and it is useless transferring great accuracy of scale by a microscopic distance. So long as good quasi-rectangular figures are considered, these may be treated as perfect rectangles. [*vide* (5)]. Let b be the breadth and l the length of the figure, in the direction of the series. Then

$$u_F = (l/b)^2.$$

The progress is l, so we may call $u_F/l = l/b^2$ the "absolute inverse efficiency" of the figure. The ratio of this to the same quantity

for a square of side b, viz., l/b, is the
"relative inverse efficiency" of scale $= l/b = H$.
Similarly, relative inverse efficiency of azimuth is $b/l = {}_aH$.

14. The inverse weight of scale after n figures is

$$U_F = \Sigma (l/b)^2,$$

and a distance $\Sigma l = n.l_m$ has been traversed.
Were the series replaced by one of r equal squares of side b_m where $n.b_m = \Sigma b$ and $r.b_m = n.l_m$, the inverse weight would be

$$U_S = \sum_1^r 1 = r = n.l_m/b_m.$$

so

$$U_F/U_S = (b_m/n.l_m)\Sigma (l/b)^2.$$

If $l = (1+f)\ l_m$ and $1/b = (1+F)/b_m$ and the distribution of f and F is random, and these quantities rarely attain the value 0·5, then

$$U_F/U_S = \left\{ 1 + \frac{1}{n}(f+F)^2 \right\} H_m \text{ approximately} = H_m \text{ nearly},$$

where $H_m = (\Sigma H)/n$.

For azimuth ${}_aU_F/\,{}_aU_S = n/r = b_m/l_m$ exactly
$= {}_aH_m$.

Intervals between Base-Lines and Laplace Points

15. A good many years ago I introduced a function "M"* to characterize the performance of geodetic triangulation. It comprised the factor $m/b^{\frac{1}{2}}$ in which "m" was Ferrero's quantity $[(\Sigma\Delta^2)/3n]^{\frac{1}{2}}$ and b was the length of a side of the figures, supposed regular and equal—an assumption not far from the truth in the case of some good geodetic series.

Under this assumption the errors of the triangulation after a course of S miles can be expressed

$p.e.$ in 7th place of log side $= 3 \cdot 32\, MS^{\frac{1}{2}}$,
$p.e.$ in azimuth $= 0 \cdot 158\, MS^{\frac{1}{2}}$ seconds,

in which the numerical factors depend on an average side length (18 miles) which was taken as a basis for M. The $p.e.$'s of displacement were also expressed, involving M as a factor.

16. We can now extend the above equations to include the cases of good quasi-rectangular quadrilaterals. It is only necessary to multiply them by the quantities (e.g., U_F/U_S) found in 14. Thus

$p.e.$ in 7th place of log side $= 3 \cdot 32\ H_m MS^{\frac{1}{2}}$
$p.e.$ in azimuth $= 0 \cdot 158\, b_m/l_m.\ MS^{\frac{1}{2}}$.

17. To ascertain the distance which should be allowed before a base-line or Laplace point is introduced, these expressions may be employed. I did this a few years ago in the case of regular figures.

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* Survey of India, Professional Paper 16, p. 91.

The formulæ deduced, modified to take a good quasi-rectangular figure into account, are now given.

Denote by S the proper distance between bases. Then

$$S.H_m^2 = 13 \cdot 5 \ (B/M)^2 + 2 \cdot 68c \ (1 + b_m/c)^2,^{*}$$

in which $B.\ 10^6$ is the probable scale of error of base-line,

c is the length of either base,

$M = m \ (18/b_m)^{\frac{1}{4}}$.

This is based on the criterion that it is worth while introducing a base when the probable error developed in the triangulation is twice that of the control.

The quantities in the formula for S are as below:—

TABLE I.—Values of $13 \cdot 5 \ (B/M)^2$ in miles.

M/B	0·2	0·3	0·4	0·5	0·7	1·0
$13 \cdot 5 \ B^2/M^2$ ...	337	150	85	54	28	14

TABLE II.—Values of $2 \cdot 68c \ (1 + b_m/c)^2$ in miles.

c \ b_m	8	10	12	15	20	25	30	35	40	45
3 ..	108	151	201	289	472	700	973	1290	1652	2509
4 ...	97	132	171	241	386	563	775	1019	1298	1954
5 ...	91	121	155	214	335	482	657	858	1086	1621
7 ..	86	111	138	185	279	392	524	676	846	1244
10 ...	86	108	129	167	241	328	429	543	671	965

Denote by S' the proper distance between Laplace points. Then

$$S' \left(\frac{b_m}{l_m}\right)^2 = 325 \ (a^2 \sec^2 \phi_n + \beta^2 \tan^2 \phi_n)/M^2,^{\dagger}$$

in which $2 \ \tan^2 \phi_n = \tan^2 \phi + \tan^2 \phi'$,

ϕ, ϕ' are latitudes of the terminal points,

$a \sec \phi$ is probable error in seconds of arc of the observed azimuths,

$\beta \tan \phi/15$ is probable error in seconds of time of the observed time difference.

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[*] *Vide* Departmental Paper No. 12, Geodesy, p. 131 A, (6).

[†] *Vide* Departmental Paper No. 12, Geodesy, p. 131 D, (12).

The relevant quantities are now tabulated with $a=0\cdot2$, $\beta=0\cdot3$, for various values of M and the latitude:—

TABLE III.—Values of 325 $(a^2 \sec^2 \phi_a + \beta^2 \tan^2 \phi_a)/M^2$.

ϕ_a \ M	0·2	0·3	0·4	0·5	0·7	1·0
50°...	1812	807	454	291	148	73
40°...	1068	474	267	171	87	43
30°...	675	300	169	108	55	27
20°...	461	206	116	74	38	19
10°...	357	157	89	57	29	14
0°...	325	144	81	52	27	13

18. Nowadays since wireless longitudes have become so simple both in execution and as regards apparatus, there are few places where a Laplace point cannot be formed. On the other hand, bases, though far more rapidly measured even on more difficult terrain than was possible thirty years ago, cannot always be introduced on account of unsuitable terrain. In such cases where bases can be introduced but sparingly, the lay-out should be such as to favour scale—that is, squat figures should be employed.

Again in high latitudes the Laplace control becomes ineffective. In that case accuracy of azimuth should be favoured by figures with the longest possible flank sides, unless indeed base-lines are impracticable where required.

Apart from these considerations there is another of great importance which I have not been able to touch—the economics of the work. Lay-out of figures and labour devoted to observations should both be considered so as to get the desired accuracy at reasonable cost in reasonable time.

PUBLICATIONS
OF THE
SURVEY OF INDIA

(Corrected up to 31st December 1931)

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	
Rupees	Annas	Shilling	Pence
0	2	0	3
0	4	0	5
0	8	0	10
0	12	1	3
1	0	1	9
1	2	1	11
1	8	2	6
1	12	3	0
2	0	3	6
2	8	4	6
3	0	5	3
3	8	6	0
4	0	6	9
4	4	7	3
4	8	7	6
5	0	8	3
5	8	9	0
6	0	9	9
6	8	10	6
7	0	11	6
7	8	12	0
8	0	13	6
8	8	14	6
9	0	15	0
9	8	16	0
10	0	16	6
10	8	17	6
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 on scale 1 inch = 16 miles approximately 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.

Index charts of the published triangulation pamphlets are given at the end.

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. Each pamphlet embraces an area of 4° x 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) (1) ...	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) (2) ...	20–24	72–76	1912	Rs. 2-0-0
47	(Bombay) (3) .	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) (4) ...	28–32	76–80	1920 (reprinted 1929)	Rs. 3-0-0
	Addendum to 53 (5) ...	...		in the press.	
54	(Agra) (6) ...	24–28	76–80	1921 (reprinted 1930)	Rs. 3-0-0

(1) includes secondary line 56 G (Wazīrābād to Islamābād); (2) includes a portion of 33 A (Nāndgaon to Ahmadnagar); (3) includes 33 A (Nāndgaon to Ahmadnagar); 33 B (Ahmadnagar to Dhond) and 26 A (Sholapur to Bijapur); (4) includes 64 H (Garhmuktesar to Aligarh); (5) includes 70 N (Mughal Sarāi to Najībābād); (6) includes 64 H (Garhmuktesar to Aligarh) and 63 B (Jhānsi to Saugor).

Levelling Pamphlets—(*Continued*).

Pamphlet		Latitude N.	Longitude E.	Published in	Price
Sheet	Distinctive name of sheet				
55	(Nāgpur) (7) ...	20°-24°	76°-80°	1912	Rs. 2-0-0
56	(Hyderābād, Deccan) ...	16-20	76-80	1912 (reprinted 1931)	Rs. 2-0-0
57	(Mysore) (8) ...	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) (8) ..	12-16	80-84	1912	Rs. 2-0-0
72	(Kātmāndu) ...	24-28	84-88	1912 (reprinted 1930)	Rs. 2-0-0
73	(Cuttack) (9) ...	20-24	84-88	1913	Rs. 2-0-0
	Addendum to 73 ...	...	...	1920	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) (10) ...	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 by lines generally produced by Gestetner at Dehra Dūn.

Serial No.	Line number	Situated in degree sheets	Published in	Price
1	52A (Ruk to Sehwān) ...	35 M & N and 40 A	1928	As. 6
2	52B (Daur to Lundo) ...	40 B & C	„	"
3	52C (Shāhpur to Mahrābpur) ...	35 N and 40 A,B,C, F & G	„	"
4	52D (Tando Alāhyār to Hyderābād)	40 C & D	„	"

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(7) includes 63 B (Jhānsi to Saugor); (8) includes 14 A (Gooty to Ongole) and 14 B (Nandyal to Atmakur); (9) includes 40 A (Jhārsugra to Purūlia); (10) includes 77 O (Calcutta to Chuadanga) and 77 P (Jessore to Bārāsat).

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 Wokali) 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 Pazunmyaung) 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	29B (Nirla to Jhalki) ...	47 J, K & O	"	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 "Levelling of Precision in India and Burma" pamphlets 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 contents of these publications see Geodetic Report Volume V).

Commencing from 1931, a new form of publication styled "**Tide-Tables for the Indian Ocean**" has been introduced *priced Rs. 3 per copy.* This comprises full tide-tables for the 40 Indian ports, hithertofore predicted by the Survey of India, and 28 other standard ports covering the whole of the Indian Ocean and far East. In addition, it also contains the non-harmonic tidal constants and tidal differences for 465 ports, and the harmonic tidal constants of 169 important tidal stations.

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

Bombay	price	-/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).

Appendix No. 1. Description of the method of comparing, and the apparatus employed.

Appendix No. 2. Comparisons of the Lengths of the 10-feet Standards **A** and **B**, and determinations of the Difference of their Expansions.

Appendix No. 3. Comparisons between the 10-feet Standards $\mathbf{I}_B$, $\mathbf{I}_S$ and **A**.

Appendix No. 4. Comparisons of the 6-inch Brass Scales of the Compensated Microscopes.

Appendix No 5. Determination of the Length of the Inch [7.8] on Cary's 3-foot Brass Scale.

Appendix No. 6. Comparisons between the 10-feet Standard Bars $\mathbf{I}_S$ and **A** for determining the Expansion of **A**.

Appendix No. 7. Final determination of the Differences in Length between the 10-feet Standards $\mathbf{I}_B$, $\mathbf{I}_S$ and **A**.

Appendix No. 8. On the Thermometers employed with the Standards of Length.

Appendix No. 9. Determination of the Lengths of the Sub-divisions of the Inch [*a.b*].

Appendix No. 10. Report on the Practical Errors of the Measurement of the Cape Comorin Base.

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

Appendix No. 1. Investigations applying to the Indian Geodesy.

Appendix No. 2. The Micrometer Microscope Theodolites.

Appendix No. 3. On Observations of Terrestrial Refraction at certain stations situated on the plains of the Punjab.

Appendix No. 4. On the Periodic Errors of Graduated Circles &c.

Appendix No. 5. On certain Modifications of Colonel Everest's system of observing introduced to meet the specialities of particular instruments.

G.T.S. Volumes—(*Continued*).

Appendix No. **6.** On Tidal Observations at Karāchi in 1865.

Appendix No. **7.** An alternative Method of obtaining the Formulæ in Chapters VIII and XV employed in the Reduction of Triangulation.—Additional Formulæ and Demonstrations.

Appendix No. **8.** On the Dispersion of Circuit Errors of Triangulation after the Angles have been corrected for Figural Conditions.

Appendix No. **9.** Corrections to Azimuthal Observations for imperfect Instrumental Adjustments.

Appendix No. **10.** Reduction of the NW. Quadrilateral—the Non-Circuit Triangles and their Final Figural Adjustments.

Appendix No. **11.** The Theoretical Errors of the Triangulation of the North-West Quadrilateral.

Appendix No. **12.** Simultaneous Reduction of the NW. Quadrilateral —the Computations.

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.*

Appendix No. **1.** Account of the Remeasurement of the Length of Kater's Pendulum at the Ordnance Survey Office, Southampton.

Appendix No. **2.** On the Relation between the Indian Pendulum Operations, and those which have been conducted elsewhere.

Appendix No. **3.** On the Theory, Use and History of the Convertible Pendulum.

Appendix No. **4.** On the Length of the Seconds Pendulum determinable from Materials now existing.

Appendix No. **5.** A Bibliographical List of Works relating to Pendulum Operations in connection with the Problem of the Figure of the Earth.

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.*

G.T.S. Volumes—(*Continued*).

Appendix No. 1. The Details of the Separate Reduction of the Budhon Meridional Series, or Series J of the North-East Quadrilateral.

Appendix No. 2. Reduction of the North-East Quadrilateral. The Non-circuit Triangles and their Final Figural Adjustments.

Appendix No. 3. On the Theoretical Errors generated respectively in Side, Azimuth, Latitude and Longitude in a Chain of Triangles.

Appendix No. 4. On the Dispersion of the Residual Errors of a Simultaneous Reduction of several Chains of Triangles.

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

Gurwāni Meridional, Gora Meridional, Hurīlāong 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.*

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

Appendices to Part I.

1. Determination of the Geodetic Elements of Longitude Stations.
2. Descriptions of Points used for Longitude Stations.
3. Comparison of Geodetic with Electro-Telegraphic Arcs of Longitude.
4. Circuit Errors of Observed Arcs of Longitude.
5. Results of Idiometer Observations made during Season 1880-81.

Appendices to Part II.

1. Situations of the Longitude Stations at Bombay, Aden and Suez
2. Survey Operations at Aden.
3. Results of the Triangulation.
4. Right Ascensions of Clock Stars.

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

Appendices to Part I.

1. Determination of the Geodetic Elements of the Longitude Stations.
2. Descriptions of Stations of the Connecting Triangulation and of those at which the Longitude Observations were taken.
3. On the Errors in ΔL caused by Armature-time and the Retardation of the Electric Current.
4. On the Rejection of some doubtful Arcs of Season 1881-82.
5. On the probable Causes of the Errors of Arc-measurements, and on the Nature of the Defects in the Transit Instruments which might produce them.

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.*

G.T.S. Volumes—(*Continued*).

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.*

Appendix No. 1. Determination of the Geodetic Elements of the Longitude Stations.

Appendix No. 2. On Retardation. (A numerical mistake was made in this appendix in the conversion of a formula from kilometres to miles: the conclusions drawn cannot therefore be upheld).

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.*

Appendix No. 1. Descriptions of Points used for Longitude Stations.

Appendix No. 2. The Longitude of Madras.

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

Appendix No. 1. On Deflections of the Plumb-line in India.

Appendix No. 2 Determination of the Geodetic Elements of the Latitude Stations of Bajamara, Bahak, Lambatach and Kidarkanta.

Appendix No. 3. On the (N-S) Difference exhibited by Zenith Sector No. 1.

Appendix No. 4. On the Value of the Micrometer of the Zenith Telescope.

Appendix No. 5. On the Azimuth Observations of the Great Trigonometrical Survey of India.

Appendix No. 6. A Catalogue of the Publications of the Great Trigonometrical Survey of India

Appendix No. 7. On the combination weights employed.

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

Appendix No. 1. Experiment to test the changes, due to moisture and temperature, in the Length of a levelling staff.

Appendix No. 2. On the erection of Standard Bench-marks in India during the years 1904-1910.

Appendix No. 3. Memorandum on the steps taken in 1905-1910 to enable movements of the Earth's Crust to be detected.

Appendix No. 4. Dynamic and Orthometric corrections to the Himālayan levelling lines and circuit; and a consideration of the order of magnitude of possible refraction errors.

Appendix No. 5. The passage of rivers by the levelling operations.

Appendix No. 6. The errors of the Trigonometrical values of heights of stations of the Principal Triangulation.

G.T.S. Volumes—(*Concluded*).

Appendix No. 7. The effect on the spheroidal correction of employing theoretical instead of observed values of gravity and a discussion of different formulæ giving variation of gravity with latitude and height.

Appendix No. 8. On the discrepancy between the Trigonometrical and Spirit-level values of the difference of height between Dehra Dūn and Mussoorie.

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.*
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.

Reports of the **Revenue Branch**—1851-1877. (Out of print).

Ditto **Topographical Branch**—1860-1877. (Out of print).

Ditto **Trigonometrical Branch**— 1861-1878.—(1861-71, 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 1877-1900 (1877-79, 1887-88, 1895-96 and 1897-98, out of print). *Price Rs. 3 per volume.* from 1900-1922 (1902-04 and 1906-08, out of print). *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 since then until 1921 have been styled (*c*) "**Records of the Survey of India**".

Annual Reports &c.—(*Continued*).

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. Vol. I of this series covers a period of three years 1922-25. *Price Rs. 6.* Subsequent volumes will be published annually. There will be in addition occasional Records volumes.

These fuller reports are available as follows:—

(*b*) **Extracts Volumes.**

1900-01—Recent Improvements in Photo-Zincography. G. T. Triangulation in Upper Burma. Latitude Operations. Experimental Base Measurement with Jäderin Apparatus. Magnetic Survey. Tidal and Levelling. Topography in Upper Burma. Calcutta, 1903. (Out of print).

1901-02—G.T. Triangulation in Upper Burma. Latitude Operations. Magnetic Survey. Tidal and Levelling. Topography in Upper Burma. Topography in Sind. Topography in the Punjab. Calcutta, 1904 (Out of print).

1902-03—Principal Triangulation in Upper Burma. Topography in Upper Burma. Topography in Shan States. Survey of Sāmbhar Lake. Latitude Operations. Tidal and Levelling. Magnetic Survey. 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.*

1903-04—Magnetic Survey. Pendulum. Tidal and Levelling. Astronomical Azimuths. 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—Magnetic Survey. Pendulum Operations. Tidal and Levelling. Triangulation in Baluchistān. Survey Operations with the Somāliland Field Force. Calcutta, 1907. *Price Rs. 1-8.*

1905-06—Magnetic Survey. Pendulum Operations. Tidal and Levelling. Topography in Shan States. Calcutta, 1908. *Price Rs. 1-8.*

1906-07—Magnetic Survey. Pendulum Operations. Tidal and Levelling. Triangulation in Baluchistān. Astronomical Latitudes. Topography in Shan States. Calcutta, 1909. *Price Rs. 1-8.*

1907-08—Magnetic Survey. Tidal and Levelling. Astronomical Latitudes. Pendulum Operations. Topography in Shan States. Calcutta, 1910. *Price Rs. 1-8.*

1908-09—Magnetic Survey. Tidal and Levelling. Pendulum Operations. Triangulation. Calcutta, 1911. *Price Rs. 1-8.*

Annual Reports &c.—(*Continued*).

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

Vol. I—**1909-10**—Topographical Survey. Triangulation. Tidal and Levelling Operations. Geodetic Survey (Astronomical latitudes and pendulum observations). Magnetic Survey. Calcutta. 1912. *Price Rs. 4.*

Vol. II—**1910-11**—Topographical Survey. Triangulation. Tidal and Levelling Operations. Geodetic Survey. Magnetic Survey. Calcutta, 1912. *Price Rs. 4.*

Vol. III—**1911-12**—Topographical Survey. Triangulation. Tidal and Levelling Operations. Geodetic Survey. Magnetic Survey. 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**—Topographical Survey. Triangulation. Tidal and Levelling Operations. Geodetic Survey. Magnetic Survey. Note on the relationship of the Himālayas to the Indo-Gangetic Plain. Calcutta, 1914. *Price Rs. 4.*

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

Vol. VII—**1913-14**—Topographical Survey. Triangulation. Tidal and Levelling Operations. Geodetic Survey. Magnetic Survey (Annual report and Government Committee's report). 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**—Topographical Survey. Triangulation. Tidal and Levelling Operations. Magnetic Survey. 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**—Topographical Survey. Tidal and Levelling Operations. Magnetic Survey. Mechanical Integrator for calculating Attractions (illustrated). Traverse Survey of the boundary of Imperial Delhi. Dehra Dūn, 1917. *Price Rs. 4.*

Vol. XI—**1916-17**—Topographical Survey. Triangulation—use of high trestle for stations and 100-feet mast signals. Tidal and Levelling Operations. Magnetic Survey. 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**—Topographical Survey. Tidal and Levelling Operations. Magnetic Survey. 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**—Topographical Survey. Tidal and Levelling Operations. Levelling in Mesopotamia. Magnetic Survey. Dehra Dūn, 1920. *Price Rs 4.*

Vol. XV—**1919-20**—Topographical Survey. Tidal work. Levelling—proposed new level net. Magnetic Survey. 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**—Topographical Survey. Tidal work. Levelling and Magnetic Survey. High Climbs in the Himālaya prior to the Everest Expedition. Mt. Everest Survey Detachment Report, 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**—Topographical Survey. Tidal work. Levelling and Magnetic Survey. 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 Bhutan 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 No. 24 Party (Sind Rectangulation). (In the press).

(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**—Computation 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.*

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.** —	853
2.—**Circular Orders (Administrative).**—	427
3.—**Circular Orders (Professional).**—	196
4.—**Departmental Orders** (appointments, promotions, transfers etc.)	

These are numbered serially and had reached the above numbers by September 1931. *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), Calcutta. *Price Rs. 1-2.*

   Part II—History of Services of Officers in the Survey of India (annually to date 1st July), 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), Calcutta. *Price Rs. 6-6.*

   Part II—Circles and parties (published annually to date 1st January), Calcutta. *Price Rs. 8-10.*

9. **List of the Publication 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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* For Departmental use only.

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. (Out of print).

5. Logarithmic Sines and Cosines to 5 places of decimals. Dehra Dūn, 1886. (Out of print).

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.—reprinted with additions, 1921. *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.*

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 boundary ribands on maps of the Survey of India, by Major F. Fraser Hunter, D.S.O., I.A. Calcutta, 1922.

13. *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.

14. **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.

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List of more important contributions by the Officers of the Survey of India &c. &c.—(*Concluded*).

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. 1, 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. 1, Jan. 1932, pages 134-137).

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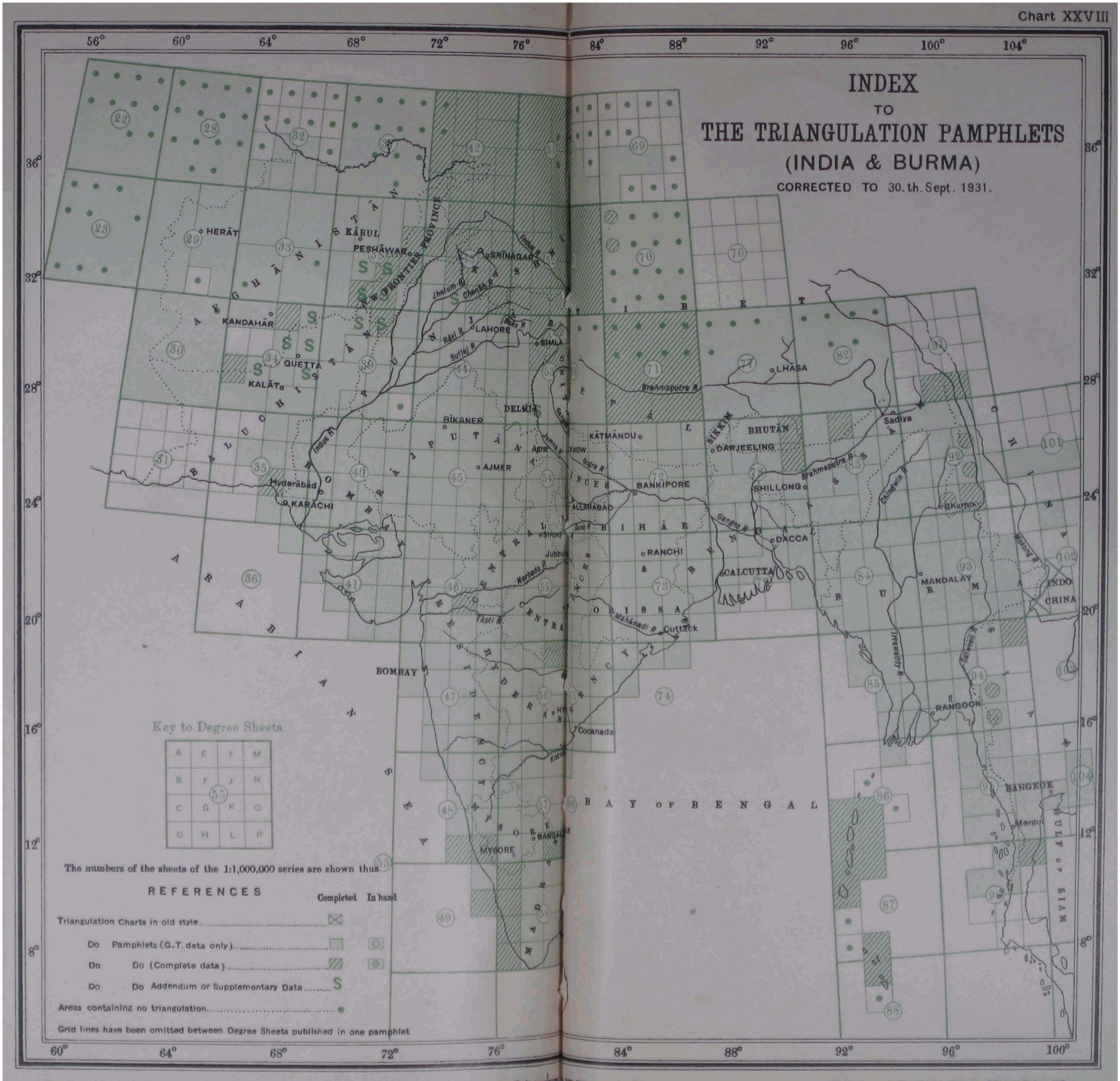
* Obtainable from the Crown Agents for the Colonies, 4 Millbank, London, S.W. 1.

† Obtainable from the Royal Geographical Society, Kensington Gore, London, S.W. 7.

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

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



INDEX
TO
THE TRIANGULATION PAMPHLETS
(INDIA & BURMA)
CORRECTED TO 30.th. Sept. 1931.

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To accompany Geodetic Report Vol. VII

INDEX TO THE TRIANGU MPHLETS
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Chart. XXIX

Scale 1/15,000,000 or 1·013 in Miles

Miles 100 50 0 100 200 400 Miles

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2

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