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INTRODUCTION

During the year 1928-29 field operations comprised Gravity observations in South and East India, Principal Triangulation in Assam and Burma, and High Precision Levelling in northern India. Three field parties were employed. At headquarters various observations were made and some research work was also carried out in addition to routine duties.

Latitude variation.—The observations with the astrolabe for the International Longitude work of 1926 also yielded values of latitude. These have been analysed (II, 4) and show a clearly marked fortnightly variation, which does not however agree in amplitude with similar results found elsewhere. Obviously all such variations require study with a view to their application as corrections to high precision latitudes; else their precision is wasted.

Possible gravity variation.—Values of g at Dehra Dūn have been determined on several occasions in direct relation to Europe as set forth in IV, 6. The extreme difference obtained, viz ·025 cm/sec^2, is rather disconcerting, and the possibility of variation of gravity at Dehra Dūn was suggested. With a view to determining whether such variation indeed existed, seven sets of observations were taken during the year (II,5). The result indicates that there is no periodic variation in g, and leaves the cause of the discrepancies alluded to unexplained.

With the help of the Riefler Clock and a Shortt Clock to be installed in 1930, it is expected that changes in g, if any, will reveal themselves without the need for special observations.

Length standards.—A mural base for determination of tape-lengths has been constructed (II,6). It is hoped to equip this with means for determining temperature coefficients.

Tidal predictions.—A change in the form of publication of Tide-tables, and considerable extension thereto, has been worked out (III,6). The first volume of "Tides for the Indian Ocean" in this new form will give predictions for 1931.

Gravity.—Chapter IV (11 *et seq.*) contains research items on gravity. Major Glennie (IV,11-14) makes use of results at 184 stations, not indeed completely covering India, but still deemed an adequate basis for preliminary enquiry.

The value of ϵ which accords best with the observations is 1/301*, and the corresponding value of equatorial gravity is 978·021 cm/sec² (cf. Helmert's 1901 formula 978·030 and $\epsilon = 1/298 \cdot 3$). Accepting any reasonable value of ϵ, any one gravity station may be used to determine a value of equatorial gravity G', and the value thus found for Indian stations shows a distinct correlation with the height H of the geoid above the spheroid. Put otherwise, the quantity $\gamma_B = \gamma_0 + KH$ (where γ_0 is the ordinary gravity expression e.g. as given by Helmert, and K is a constant) fits the observational results for India better than does γ_0. The value of K naturally depends on the spheroid of reference.

Thus for International spheroid $K = \cdot 0019$ } H being expressed
and for Survey of India spheroid $K = \cdot 0021$ } in feet.

Major Glennie then proposes the quantity $\gamma_D = \gamma_C + KH$ where γ_C is the formula value including correction for topography compensated according to Hayford's hypothesis. Major Glennie points out that K is empirically determined to suit the Indian region, and does not claim any further universality for it. He attributes the cause of the main features of the geoid in India to deep-seated causes (IV, 13): and so considers $g - \gamma_D$ as a measure of those density anomalies which lie closer to the surface. The value of $g - \gamma_D$ may then be expected to follow the surface density anomalies to some extent.

If the details of these—their mass and extent, particularly in depth—were known from geological sources, they would afford a check on Major Glennie's contention regarding $g - \gamma_D$. Unfortunately the depth is not known ordinarily, and so the check is not quantitatively complete. In all the places where there is geological knowledge to go on, $g - \gamma_D$ shows some degree of accord which is absent with $g - \gamma_C$. It would appear then that $g - \gamma_D$ provides some evidence as to geological densities in India.

In Section II, I have considered the question more theoretically and shown that the relation $\gamma_D = \gamma_C + KH$ can only be strictly true if the irregularities of the geoid can be represented by a single Laplace function, and that this must be the 37th to yield the value of K found by Major Glennie. This corresponds to a waviness of the geoid of mean angular period 10°, while a glance at the chart of the geoid suggests an angular period of 12° as the main feature. It is not surprising that the expression $\gamma_C + KH$ should not absolutely agree with gravity found at all places, but its agreement to a fairly approximate extent is natural.

The matter is attacked differently by Capt. Bomford in Section III. Accepting the geoid as found from deflection observations, he has carried out a solution giving a set of crustal anomalies which are competent to explain this geoid. The solution cannot be exactly true owing to limitation of the area surveyed: but apart from portions close to these limits—generally speaking the coast line and the Himālaya,—it can hardly be far from the truth.

* This is precisely Everest's value derived from his Great Arc Series and the Greenwich-Formentara arc.

The solution is interesting in two respects:—

(*a*) It denies compensation in the restricted form postulated by Hayford, while allowing regional compensation at a suitable depth as a possibility.

(*b*) It provides a basis of computation for gravity at any point within the region considered.

As regards (*a*) I have already drawn attention to the failure of Hayford's isostasy in continental India (Geophysical Meeting R.A.S. of 20-4-28: "Observatory" June 1928). It certainly shows the vainness of attempting to compute the form of the geoid or the value of gravity in areas unsurveyed merely from the ordinary formula combined with the topographic effect and its compensation on Hayford's basis, as has been proposed (Bowie, American Journal of Science No. 81, Sept. 1917). Conditions of approximately perfect Hayford isostasy encountered in the United States are not met with in peninsular India: and there does not appear reason to assume them anywhere, until observation has indicated their existence.

As regards (*b*) the computation has been performed and results are exhibited in Chart XV. The deduced values of gravity are not identical with those found from observation (differing by a quantity *E*) for a variety of reasons explained in IV, 24. These may be divided into two classes in the second of which (*c*) falls. Items (*a*), (*b*), (*d*) and (*e*) are due to limitation of our general knowledge. Item (*c*) however is a proper goal of pendulum work— to determine the local density anomaly. Accordingly one may hope that (*a*), (*b*), (*d*) and (*e*) are unimportant in most cases, and that they will be increasingly so as observations are extended: in which case the anomaly of gravity from its value computed from Chart XV would be a fair measure of item (*c*), the local density anomaly.

This anomaly *E* is very analogous to Major Glennie's $g-\gamma_D$. The quantity *E* however is not empirical as is $g-\gamma_D$ so far as Major Glennie has gone: though a rough representation of the waviness of the geoid gives a theoretical basis for the latter. However *E* goes further and takes full account of the determined facts, in doubt only so far as limitations IV, 24 (*a*), (*b*), (*d*) and (*e*) indicate. It may be regarded, more particularly than $g-\gamma_D$, as the local anomaly. Even so it is not easy to say exactly what is meant by local e.g. we cannot say to what depth an anomalous density persists, or distinguish between a mile thickness of a given anomalous density and a few miles thickness of a less anomalous density. Thus we cannot expect a close correlation between geological densities of unknown depth and either *E* or $g-\gamma_D$. Captain Bomford reaches this conclusion from a somewhat different line of attack (IV, 25).

Any system of anomalous densities within the geoid (or any residue of these after any general correction such as for topography and hypothetical compensation on any theory), can be represented, so far as effects external to the geoid are concerned, by a hypothetical skin density applied to the geoid: and the gravity anomaly at any point on the geoid is a definite measure of this. The anomaly at a point above the geoid gives a generalised value of the skin anomaly in the neighbourhood. That is as much as geodetic observations can tell precisely. It is another matter to find the actual density anomalies, their amount and distribution. I have shown (IV, 17) the relation between actual anomalies, distributed uniformly along verticals, and their condensation on the surface: and it is possible to do the same for other systematic distributions. For long period anomalies the vertical distribution is unimportant as regards external effect: more specifically the factor $1-\pi d/l$ (see IV, 17 (10)) indicates this difference if $\pi d/l$ is considerably less than unity, d being the depth and l the length of a wave of anomaly. It is clear that in such cases the pendulum cannot discriminate as to the actual crustal distribution of anomaly of density.

But in so far as these are wide spread, their effects are removable either by Capt. Bomford's computation (IV, 24) or to a less degree in the particular case of India by Major Glennie's *KH*. The residuals E or $g-\gamma_D$ are much more localised and, given their values at points close together compared with the depth of the casual anomalies, the location of these latter and their amounts could be estimated, restricting their amounts to what can reasonably be expected to occur.

This raises the question of the proper spacing of pendulum stations. Formerly the Survey of India had no prospect of covering its area with a high density of stations, but Major Glennie's labours have led to a much greater out-turn than was formerly possible. The work of the coming season (1929-30) will add some 20 stations, filling a considerable gap between Bombay and Madras, and within 5 years there should be an average density of 1 pendulum station to every 70-mile square. For the distribution of crustal anomalies of density even this is too sparse, except for a generalised enquiry. In 1930-31 observations with the modified Eötvös balance—the Gravity Gradiometer—will be made in conjunction with pendulum observations. It is hoped that they will locate areas of special interest for further study. They will also assist in the location of anomalies close to the surface, leaving the pendulum to tell the story of what is lower down. But even for this a considerably greater station-density than that referred to above, viz 1 in every 70-mile square, will probably be necessary. It will be possible to provide these in areas which show irregularities.

Triangulation (V).—Of the two series of principal triangulation, the Chittagong series was nearly completed, two triangles being unavoidably left for the coming season. The revision of the Mong Hsat series, whereby it was hoped to effect a junction with the triangulation of Siam, failed, and has to be repeated in the coming season. Two geodetic model Wild theodolites were employed. Both instruments developed a serious stiffness in the working of the vertical axis, presumably as a result of tropical conditions. In the case of the one used on the Mong Hsat series, this trouble was sufficient to reduce the accuracy below the standard required for the work. The observer, failing to realise this, carried on in a vain attempt to complete the programme. This instrument has been replaced by Mr. Wild and good results are anticipated for the coming season, when a more complete junction with Siam of both the Mong Hsat and Great Salween series is being attempted. Further connections with Siam in latitudes 16° and 10° 30′ are also under consideration.

Special methods have been applied to the height computations of the Chittagong series owing to the fact that observations could not on all occasions be made at the time of minimum refraction on account of bad visibility (V, Appendix).

High Precision Levelling.—Normal progress has been made in High Precision Levelling of which nearly half the total mileage is now completed. A subsidence at Ambāla of one or two inches since 1910 is revealed, following a subsidence of 7 inches in the previous 50 years (VI, 4). Further attempts to reconcile the levelling between Sukkur and Hyderābād has not led to a definite conclusion (VI, 5). Two short hill circuits with variations of 5,000 feet in height were observed to ascertain the accuracy that can be attained in such work, and to provide examples of the peculiar effect of varying gravity in such cases (VI, 6). The results have thrown doubt on the reliability of wooden staves. Any systematic error in these is of vital importance where the line is steadily rising or falling: as is essentially the case in hill circuits. Wooden staves have served to give good results in levelling in the plains, but have failed in these hill circuits. Subsequent test at Dehra has revealed considerable diurnal change in length (VI, 7). For the latter purpose invar staves seem the proper alternative, and test with these will be made next season. Hitherto the Survey of India has had none of these, but 3 pairs are expected at the end of 1929.

Effect of gravity on height determination.—In high precision levelling it has been usual to apply corrections for the difference between dynamic and orthometric height, for which purpose a formula value of gravity, uncorrected for topography, has generally been employed. In the presence of larger topographical features the gravity formula does not accord well with actual gravity. Under these conditions special difficulties arise: and these would not be entirely removed even if a surface value of gravity were available at every point of the line. A discussion of the case is given in VII Section I with application to the case of height of Mussoorie above Dehra, showing a correction of 0·7 feet in the orthometric height. A corresponding correction (VII Section II) is necessary when the geoidal form is computed from deflection observations at the surface. The effects of the rigorous allowance for the variation in gravity on orthometric height above the geoid, found from spirit-levelling or from triangulation prove to be the same (VII Section III): and so these refinements do not assist in reconciling the two. The correction appears to have only an academic interest. Without it we are in a position to express the height of a point above a definite reference figure, but not its height above sea-level, whose form can only be computed at considerable labour with certain assumptions as to the variation of gravity between the geoid and the earth's surface.

Personnel.—The personnel of the Geodetic Branch during the year is given in the following pages.

DEHRA DŪN,
Dec. 1929.

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

PERSONNEL* OF THE GEODETIC BRANCH, 1928-29.

Director, Geodetic Branch

LT.-COLONEL R. H. THOMAS, D.S.O., R.E., from 15th October to 13th Dec. 1928.
Dr. J. DE GRAAFF HUNTER, M.A., Sc. D., F. Inst. P., to 14th October 1928 and from 14th December 1928.

COMPUTING AND TIDAL PARTY
(RECORDS AND RESEARCH)

Class I Officers.

Lt.-Colonel C. M. Thompson, I.A., in charge to 28th April 1929.

Captain G. Bomford, R.E., in charge from 29th April 1929.

COMPUTING SECTION.

Upper Subordinate Service.

Mr. M. Acharya.

Mr. R. C. Ray.

Mr. M. Chatterjee.

Mr. S. Mitra.

Mr. T. N. Sharma, B.A.

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

Mr. R. K. Bhattacharya, B.A.

Mr. C.B. Madan, B.A., Geodetic Computer.

Mr. K. G. P. Rao, B.A., (on probation) from 26th October 1928.

Lower Subordinate Service.

8 Computers.

TIDAL SECTION.

Class II Officers.

Mr. R. B. Mathur, B.A., Tidal Assistant, to 29th October 1928.

Mr. D. H. Luxa, Tidal Assistant, from 30th October 1928.

Lower Subordinate Service.

11 Computers.

OBSERVATORY SECTION.

Class II Officers.

Mr. R. B. Mathur, B.A.

Upper Subordinate Service.

Mr. H. C. Deb, B.A.

Mr. P. K. Chowdhury, to 31st July 1929.

Mr. H. C. Banerjea, B.A., from 1st August 1929.

Lower Subordinate Service.

7 Computers.

Magnetic Observatory.

Mr. K. N. Mukerji, M.A.

1 Computer.

OFFICE AND P. & M. SECTION

Upper Subordinate Service.

Mr. B. B. Lal.

Lower Subordinate Service.

2 Computers and 3 Clerks.

DRAWING SECTION.

Surveyor Faiz-Ullah.

6 Draftsmen.

14 PARTY (PENDULUM)

Class I Officers.

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

Lower Subordinate Service.

3 Computers etc.

15 PARTY (TRIANGULATION)

Class I Officers.

Captain G. Bomford, R.E., in charge from 17th December 1928 to 29th April 1929.

Mr. N. R. Mazumdar, in charge from 29th April to 10th August 1929.

Lieut. I. M. Cadell, R.E., in charge from 10th August 1929.

Mr. B. L. Gulatee, M.A. (Cantab.), to 5th September 1929.

Class II Officers.

Mr. N. R. Mazumdar, from 29th April 1929.

Mr. P. K. Ghosh, B.A. (Cantab.), to 11th August 1929.

Upper Subordinate Service.

Mr. H. C. Banerjea, B.A., to 31st July 1929.

Mr. L. R. Howard.

Lower Subordinate Service.

4 Computers etc.

17 PARTY (LEVELLING)

Class I Officers.

Dr. J. de Graaff Hunter, M.A., Sc. D., F. Inst. P., in charge from 15th October 1928 to 1st January 1929.

Lt.-Colonel C. M. Thompson, I.A., in charge from 29th April to 21st May 1929.

Lieut. I. M. Cadell, R.E., in charge from 2nd January to 28th April 1929, and without charge from 13th May to 10th August 1929.

Mr. N. R. Mazumdar, in charge to 14th October 1928.

Mr. H. P. D. Morton, in charge from 22nd May 1929.

* Excluding No. 2 D.O., Publication and Stores, F. M. O., and 20 Party.

17 PARTY (LEVELLING)—*(contd.)*

Class II Officers.

Mr. N. R. Mazumdar, to 28th April 1929.

Mr. Abdul Karim, B.A., to 14th January 1929.

Upper Subordinate Service.

Mr. L. D. Joshi.

Mr. Abdul Majid, to 31st May 1929.

Mr. A. A. S. Matlub Ahmad, from 24th June 1929.

Mr. J. N. Kohli.

Mr. B. P. Rundev.

Mr. Muhammad Faizul Hasan.

Mr. I. D. Suri.

Lower Subordinate Service.

18 Computers, levellers etc.

TRAINING

Class I Officers under instruction.

Lieut. R. H. Sams, B.SC., R.E., from 10th March 1929.

Lieut. C. J. Price, R.E., from 9th March 1929.

Lieut. C. A. K. Wilson, R.E., from 9th April 1929.

TRAINING SCHOOL

Mr. S. F. Norman, Survey Instructor, to 28th October 1928.

Mr. L. Williams, M.B.E., Survey Instructor, from 29th October 1928.

Chapter I

COMPUTATIONS AND PUBLICATION OF DATA

BY CAPTAIN G. BOMFORD, R.E.

1. Lambert grid.—The Computing Office has been largely occupied with computations in connection with the Lambert grid for military use, and with the preparation of forms for computation in terms of the grid. For some years the method of computing surveys on active service has been the subject of discussion and experiment. In 1924 the "Minute Mesh" was introduced. This is a reference system consisting of meridians and parallels at one minute intervals: descriptive references are given by a convenient system of lettering, and all survey computations are done in spherical terms in the usual way. From the survey point of view this system has many advantages: there is no limit to the extent of the mesh, all existing data are already in terms of the mesh without conversion, and all existing methods, tables and forms are immediately applicable to work on the mesh. From the point of view of the artillery there is the objection that the range and bearing of a target cannot be computed from the simple formulæ, Distance = $(\Delta N^2 + \Delta E^2)^{\frac{1}{2}}$, Bearing = $\tan^{-1} \Delta E/\Delta N$. Also these formulæ cannot be used for traverse and other rough work without subsequent conversion of co-ordinates.

In 1926, in order to meet the requirements of the artillery, a Lambert grid* was adopted, covering 8° of latitude in the North-West Frontier (Origin 33° 30′, 66° 00′). At this time it was intended to use the mesh for survey and general purposes, and the grid for artillery purposes only.

In 1928 it was realised that this duplication of reference systems was unsatisfactory, and since the artillery would not adopt the mesh, it was decided to use the grid for all arms. In view of the well-known inaccuracy of computations in rectangular co-ordinates, it was first intended that the surveyors should continue to compute their triangulation in spherical terms, converting spherical co-ordinates to rectangular as soon as they were determined. This conversion is laborious, and in a survey exercise held in 1927 the prompt completion of all computations was found to be a considerable difficulty.

The system of computation which has now been adopted, is that

* i.e. a reference system which consists of true squares when exhibited on a map which is drawn on a Lambert projection with the same origin. On the ground, or on other maps the squares are not quite perfect.

all computations are carried out directly in rectangular co-ordinates, the necessary accuracy being obtained by the conversion of observed data into grid terms, before starting computation. Thus lengths (such as bases) measured in true yards, are at once converted into "grid yards" by correction for the scale error of the projection in that latitude. Similarly, measured angles are converted into grid angles by small corrections dependent on the latitude and the easting of the points observed. The simple rectangular formulæ for distance and bearing are then rigorously applicable to the corrected angles and distances, and rectangular computations are as accurate as, and a little more rapid than, the usual spherical computations, with the advantage that no subsequent conversion is required.

So far as survey work is concerned, a grid covering 16° of latitude would present little difficulty: beyond this the scale and angular corrections would begin to be inconveniently large. But the artillery do not care to have computed ranges in error by more than 1 part in 800, nor do they care to apply a scale factor to computed ranges, and consequently the grid is at present limited to 8° belts. For training purposes, and in order to be ready for all emergencies, a system of overlapping 8° grids has been projected to cover all India and Burma, but little work has yet been done on any but the North-West Frontier grid (Origin 32° 30′, 68° 00′).

Although computations on the grid are as rapid as computations in spherical, the adoption of the grid has resulted in a great deal of preparatory computation, which is still very far from complete. In addition to the preparation of special tables and forms, it will presumably necessitate the conversion of existing spherical data to grid terms in all training areas and possible war areas; for this conversion is a laborious computation which cannot prudently be left until after the outbreak of war. Preparatory work of this nature, undertaken by the Computing Office during the year under report, is described in the following paragraphs.

Table for S.—The grid distance S between two points of equal longitude whose meridian distance is m, one being on the central parallel λ_0, has been computed by the formula*

$$S = m + \frac{m^3}{6\,\rho_0\,\nu_0} + \frac{m^4 \tan\lambda_0 (1 - 4e^2\cos^2\lambda_0)}{24\,\rho_0\,\nu_0^2 \dagger} + \frac{m^5(5 + 3\tan^2\lambda_0 - 3e^2 - e^2\cos^2\lambda_0)}{120\,\rho_0^2\,\nu_0^2}$$

$$+ \frac{m^6 \tan\lambda_0 (7 + 4\tan^2\lambda_0)}{240\,\rho_0^2\,\nu_0^3} + \frac{m^7(60\tan^4\lambda_0 + 180\tan^2\lambda_0 + 61)}{5040\,\rho_0^3\,\nu_0^3}.$$

This formula has been given by M. H. Roussilhe in the Proceedings of the 2nd meeting of the Geodetic and Geophysical Union. Sufficient terms have been used to give an accuracy of 0·1 yards. For this purpose the formula given is sufficient up to more than 8° from the origin, and several terms have generally been negligible.

* On a grid with a central scale factor this expression requires to be multiplied by that factor.

† $\rho_0^2\,\nu_0^2$, as given by Roussilhe is clearly a misprint.

Authorities have differed regarding the combination of ρ_0 and ν_0 in the denominators, and consequently the terms as far as that in m^5 have been verified (by Mr. P. K. Ghosh) and found correct: in later terms the distinction between ρ_0 and ν_0 is of no consequence.

The table (43 Sur.) has been completed between lats. 28° and 36° 30 at 2 minute intervals.

Table for m.—In order to avoid discrepancies which may cause any possible inconvenience, it has been necessary to compute a fresh table of meridian distances on Everest's spheroid. The Survey of India Auxiliary Tables (4th edition) give values of the radius of curvature of the meridian at 10 minute intervals to one decimal of a foot, and the table of *m* has been built up from this. Meridian distances from the equator are given at intervals of 2 minutes to lat. 45°, and are correct to 0·01 yards. They have been checked by the Royal Geographical Society's conversion tables at 28° 30′, 30° 30′, 34° 30′ and 36° 30′, with discrepancies of 0·003, 0·002, 0·002 and 0·001 yards respectively.

An error of a yard in his meridian distance for the equator is, of course, of no interest to a triangulator on active service, but an error of this amount in the relative positions of two near stations might be very undesirable. Consequently the table of *S* gives tenths of yards, and since future developments can never be foreseen, it has been thought proper to make this table absolutely correct as far as it goes.

Table for scale factor.—A table (44 Sur.) has been made giving the scale error, scale factor and log scale factor of the North-West Frontier grid, at intervals of 10 minutes of latitude.

Table of angular corrections.—A table (44 A Sur.) has been made giving the corrections necessary to convert observed angles to grid angles in the North-West Frontier grid area.

Table of convergence.—A table (44 B Sur.) has been made giving the convergence for the North-West Frontier grid between longitudes 58° E. and 78° E. at intervals of 2′. This table is intended for the conversion of true bearings to grid, not for use in the conversion of co-ordinates.

Table of sheet corners.—A table (44 C Sur.) has been made giving the rectangular co-ordinates of all 15 minute squares in the area 28° N. to 36° 30′ N. and 60° E. to 76° E. This table is intended for gridding spherical maps and vice versa.

Table of cutting points.—Draftsmen have found difficulty in the use of the table of sheet corners, and a start has been made with a table giving the latitude at which all 10,000 yard lines of grid northing cut every 15 minute meridian, and the longitude at which every 10,000 yard line of easting, cuts every 15 minute parallel. The construction of this table is proving laborious. It has nearly been completed between lats. 28° N. and 36° 30′ N., and longitudes

41° E. and 78° E, but the rest of India and Burma still remains to be done. For the north and south grid lines direct computations have been made along every fourth parallel (i.e. every degree) for every tenth grid line (100,000 yards), the remaining entries being derived by interpolation. This interpolation, which involves second differences, has been carried out on a Nova-Brunsviga IVa calculating machine. A similar procedure has been followed for the east and west grid lines.

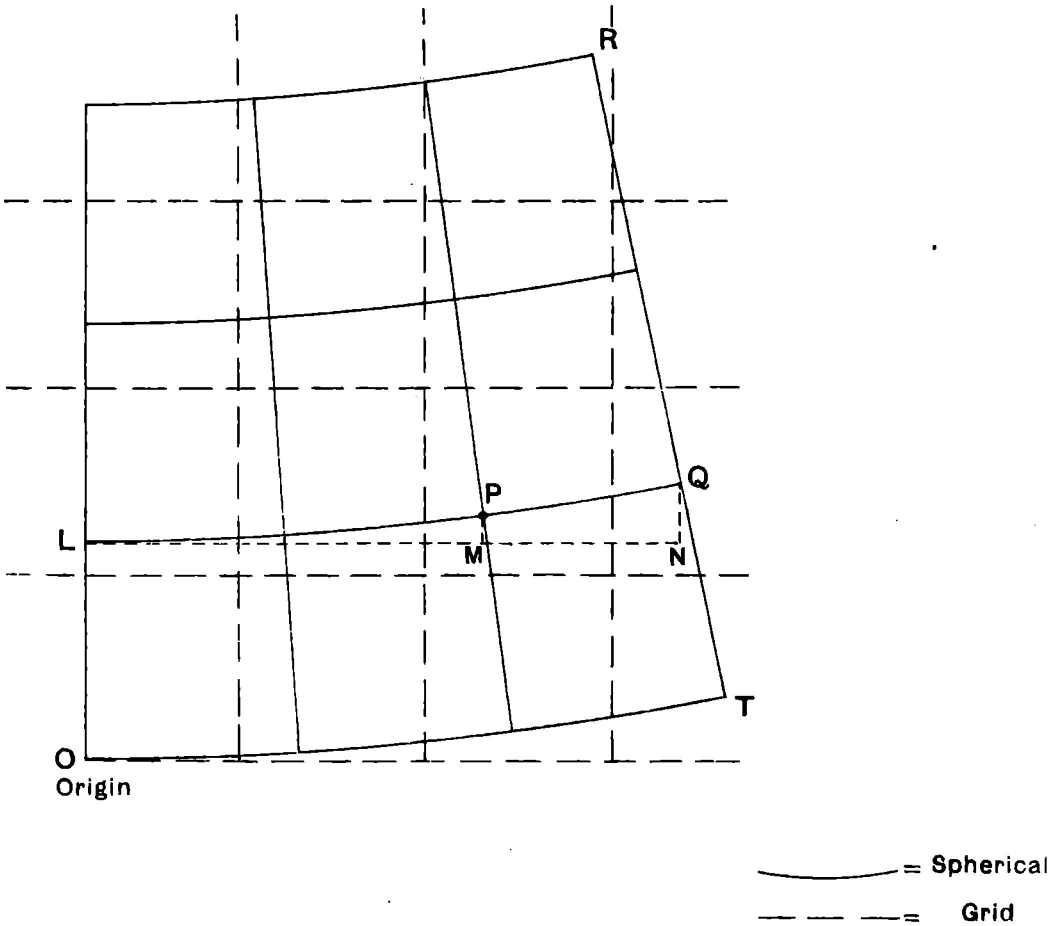
Forms.—With the co-operation of the officers of the Frontier Circle a set of forms has been prepared for use in conjunction with the Lambert grid. Some are very similar to the ordinary forms of the Survey of India, while others differ considerably. For certain observations, e.g. time and latitude, the ordinary forms will be used unmodified. The forms prepared are:—

1.	Lamb	Spherical to rectangular.
2.	,,	Rectangular to spherical.
3.	,,	Computation of distance and bearing.
4.	,,	Solution of triangles.
5.	,,	Computation of co-ordinates and heights.
6.	,,	Computation of cutting points and heights, for semigraphical.
7.	,,	Bearing from Sun, given altitude.
8.	,,	Bearing from Polaris, given time.
9.	,,	List of co-ordinates.
10.	,,	Descriptions of points for triangulation.
11.	,,	Angle book.
12.	,,	Progress and record.
13.	,,	Bearing from Sun, given time.
20.	,,	Traverse field book.
21.	,,	Traverse set-up.
22.	,,	Northing, easting and height by logs.
23.	,,	Northing and easting by tables.
24.	,,	Traverse synopsis.

Detailed specimens of the above forms have been prepared for the press, but they have not yet been printed.

Avoidance of 8-figure logarithms.—In a longitude differing greatly from that of the origin, the conversion of spherical co-ordinates to rectangular on the usual form may necessitate the use of 8-figure logarithms, whose use is slow and which may not be available. Thus at 8° from the origin, the use of 7-figure logs may introduce an error of two or three tenths of a yard, which may cause appreciable error in the mutual distance of two near points. Methods for remedying this difficulty, without introducing more than one origin in the same latitude, are now under consideration. In the first method, which is being developed by Mr. H.C. Deva, the eastings are tabulated of all points at intervals of 1 minute of latitude, along a certain meridian RT (see Chart I.) distant (say)

Conversion of Coordinates



100,000″ from O, the origin. The distances OL and QN are also tabulated. Then for any point P the easting $LM = LN \cdot L_P / 100{,}000$ + (a small tabulated correction), where L_P is the difference of longitude between P and O. Similarly, the northing of $P = OL + QN \cdot L_P^2 / (100{,}000)^2$ + (a small correction). If a multiplying machine is available, this computation is very rapid, involving no tables but the special tables provided. Without a machine 8-figure logarithms are required, but no trigonometrical tables.

In the second method, which is being developed by Mr. K. G. P. Rao, the co-ordinates and convergence are tabulated at sub-origins 4° apart. The co-ordinates of any point relative to the nearest sub-origin can be computed with 7-figure logarithms in the usual way, and can then be converted to the principal origin by the ordinary formulæ for change of axes and origins in rectangular co-ordinates. Combination of the original conversion with the change of axes, results in some simplification of the form.

The first of these two methods is likely to be the most satisfactory, if a calculating machine is available, and possibly so, if 8-figure logarithms are available. The second method constitutes a standby for use in other circumstances. As mentioned above it is to be hoped that all necessary conversion of co-ordinates will be done at leisure in time of peace, and that hardly any will be necessary for war. Nevertheless, to avoid complicating the work of the field parties, it has been decided to limit the longitudinal extent of grids to 16°, except that of the N. W. F. grid in the distant parts of which there are no data to convert.

Mr. R. C. Ray has been in charge of all the computations in connection with the Lambert grid.

2. Triangulation: Best hour for horizontal angles.—Triangulation signals generally appear to be more steady by night than by day, a fact which leads to the conclusion that the night is probably the best time for horizontal angles. At the same time night work is often inconvenient, it is apt to be slower than day work, and analogy with vertical angles shows that mere steadiness is not in itself a proof of reliability.

From a theoretical point of view, closer examination shows that night may be expected to be the best time. Just as abnormal vertical refraction is caused by an abnormal vertical air density gradient, which in turn is caused by an abnormal temperature gradient, so is horizontal refraction caused by a horizontal density or temperature gradient. By day, such abnormalities are caused by hot air rising from the ground, and they result in an unsteadiness of the signal. When the ray is close to the ground, the unsteadiness may be so great at midday that observations are clearly impossible. Under other circumstances the unsteadiness may be sufficiently small to justify the hope that the casual errors of bisection will be eliminated in the mean of a large number of readings, but there remains the risk that some accident in the underlying ground may cause a more persistent rising of hot air on one side of the ray than on the other, with consequently a persistent tendency to error in all intersections. At night there are no streams or eddies of rising air, and, unlike a vertical density gradient, a large horizontal gradient is only in stable equilibrium in the immediate neighbourhood of some source of heat or cold. Thus, it may be expected that for rays close to the ground night observations should be better than day, and that for rays in high hills there should not be much difference, with perhaps a slight preference for night. It is to be remarked that when a ray grazes the side of a cliff or sloping hill the horizontal refraction is likely to be of opposite sign by night and by day, and consequently observations of such rays should be made at both times; a good cancellation can hardly be expected, but at least the weakness should be shown up.

To verify theory, abstracts have been made from the observations of four series of triangulation each representing a different type of country. Observations have been classified as morning (sunrise to 11 hours), afternoon (16 hours to sunset) and night: in India primary observations have seldom been made between 11 & 16 hours. From the measures so classified, the morning, afternoon and night triangular errors have been found for 6 or 7 triangles in each series. From each triangular error the probable error of a single measure has been deduced by the formula, $E = \epsilon \sqrt{1/n^2_1 + 1/n^2_2 + 1/n^2_3}$, where E is the probable value of the triangular error, ϵ is the probable error of an angle, and n_1, n_2, n_3 are the number of measures of each angle. The results are given in Tables 1 to 4. As regards night *versus* afternoon, night is seen to be markedly the best in the very low rays over the bare ground of the Great Indus series: in the other three series the afternoon is slightly the better, but not so much that the fact can be considered well established. Morning observations are wanting in the two low series: in the jungle covered hills of the Great Salween they appear to be slightly the best, and in the barren hills of the Kalāt Longitudinal they are much the worst. The evidence is not sufficient to be conclusive: so far as it goes it indicates that morning observations are safe in jungly hills, and that they are dangerous in bare hills, as is not unreasonable. In barren plains there is often mirage in the morning, and observations at that time would obviously be bad.

3. Hayford deflections.—Several hundred Indian deflection stations still remain, for which no topographical or isostatic reduction has yet been made. The value of these reductions does not depend on the acceptance of the existence of perfect isostasy, for the effect of visible topography must be eliminated, whatever system is adopted. During the past two years occasional opportunities have arisen for undertaking a little of this work, but no extensive progress has been made. The results are put on record in Table 5.

It is intended to publish typewritten lists giving full details of the heights of zones and compartments of these and other gravity and deflection stations for which such data have not yet been published.

4. Computation forms and Tables.—The method of computing astrolabe observations has been examined in detail, and a number of improvements introduced. For example, the small nutation corrections, which have hitherto been applied to each star individually, are now applied as a correction to the final results. Similarly, when interpolating declination and R. A. from a 10 day ephemeris, it is convenient to ignore the fraction of a day which arises from the difference between the longitude of the place of observation and that for which the ephemeris has been prepared; this is now the practice, and the resulting error is corrected at the end. Form 4 Ast. has been remodelled and a new form 12 Ast. prepared.

In addition to the Lambert tables referred to in para 1, five other charts and tables have been prepared, in connection with astrolabe, longitude, and pendulum computations.

5. Triangulation and levelling pamphlets.—The compilation of the Mesopotamian triangulation has now been completed, although all the pamphlets have not yet been published. The compilation of triangulation in Persia has been begun. 20 Indian pamphlets covering 32 degree sheets have been prepared for reproduction by photozincography to meet shortage of stock.

19 small pamphlets totalling about 1,729 miles of secondary levelling data have been reproduced by Gestetner. One primary pamphlet has been reprinted, and the data of nine lines totalling about 1,063 miles have been printed in the form of addenda to existing primary pamphlets.

6. Drawing Section.—Six Indian and seven Mesopotamian degree sheet triangulation charts have been drawn, and one levelling chart. 17 charts have been prepared in illustration of Geodetic Reports Vols. III and IV. About 70 other indexes, diagrams and figures have been prepared for other purposes.

7. Miscellaneous publications.—Lieut-Colonel C. M. Thompson has compiled a pamphlet describing the formulæ and methods of computation used in connection with the Lambert grid. He has also compiled notes on Astronomy and Astronomical Computations for the use of officers under instruction.

A new edition of the Topographical Handbook, Chapter III (Triangulation) has been prepared, but not yet sent to press. Geodetic Reports Volumes III and IV, and Professional Papers 22 and 24 have been seen through the press.

TABLE 1.—*Kalāt Longitudinal Series. Barren hills.*

Triangle		1	2	3	4	5	6	7	
Morning	E	2·30	2·62	0·44	1·00	1·07	0·36	1·17	Morning mean $\epsilon = 3''·69$
	n_1	17	42	29	32	36	34	28	
	n_2	24	28	38	28	19	31	29	
	n_3	18	21	26	22	30	16	21	
	ϵ	5·82	8·00	1·40	2·98	3·18	1·02	3·41	
Afternoon	E	...	3·37	0·01	1·44	0·16	0·34	0·50	Afternoon mean $\epsilon = 1''·61$
	n_1	...	2	11	10	2	12	16	
	n_2	...	26	14	16	20	16	10	
	n_3	...	19	18	24	27	16	23	
	ϵ	...	4·38	0·02	3·19	0·21	0·74	1·10	
Night	E	0·09	0·16	0·87	0·21	0·58	0·25	0·97	Night mean $\epsilon = 1''·91$
	n_1	58	64	64	51	50	40	67	
	n_2	28	68	80	64	55	62	49	
	n_3	65	57	60	55	52	53	34	
	ϵ	0·34	0·73	4·11	0·91	2·42	1·02	3·81	

TABLE 2.—*Great Indus Series. Flat barren plains.*

Triangle		1	2	3	4	5	6	7	8	
Afternoon	E	0·31	1·55	0·59	1·45	0·82	0·19	0·41	0·63	Afternoon mean $\epsilon = 1''·44$
	n_1	14	10	17	11	12	10	11	11	
	n_2	19	17	10	7	13	15	11	11	
	n_3	6	9	14	14	18	11	9	11	
	ϵ	0·57	2·98	1·23	2·63	1·76	0·37	0·76	1·20	
Night	E	0·51	0·16	0·21	0·24	0·04	0·16	0·09	0·19	Night mean $\epsilon = 0''·51$
	n_1	17	19	15	22	18	22	20	22	
	n_2	14	14	25	27	17	18	20	21	
	n_3	24	25	20	17	12	19	21	20	
	ϵ	1·23	0·40	0·53	0·64	0·09	0·41	0·23	0·50	

TABLE 3.—*East Calcutta Longitudinal Series. Flat jungle plains.*

Triangle		1	2	3	4	5	6	
Afternoon	E	0·09	0·79	0·24	0·20	0·76	0·40	Afternoon mean $\epsilon = 0''.98$
	n_1	17	20	23	22	18	14	
	n_2	28	19	25	20	12	11	
	n_3	20	27	16	13	10	18	
	ϵ	0·24	2·12	0·63	0·48	1·56	0·86	
Night	E	1·15	0·09	0·09	0·81	0·53	0·78	Night mean $\epsilon = 1''.20$
	n_1	14	17	12	9	11	18	
	n_2	18	12	5	5	19	20	
	n_3	11	8	11	19	20	15	
	ϵ	2·46	0·17	0·15	1·34	1·21	1·88	

TABLE 4.—*Great Salween Series. Jungle hills.*

Triangle		1	2	3	4	5	6	
Morning	E	0·03	1·00	0·17	0·55	0·15	1·36	Morning mean $\epsilon = 1''.15$
	n_1	16	12	12	12	16	12	
	n_2	18	7	21	19	18	14	
	n_3	14	17	22	18	14	17	
	ϵ	0·07	1·87	0·41	1·26	0·34	2·94	
Afternoon	E	0·12	0·12	0·54	0·43	1·37	0·21	Afternoon mean $\epsilon = 1''.26$
	n_1	8	27	29	21	28	11	
	n_2	7	11	15	21	24	9	
	n_3	18	17	26	24	23	29	
	ϵ	0·21	0·28	1·44	1·16	3·99	0·43	
Night	E	1·61	0·02	0·24	0·19	0·56	0·22	Night mean $\epsilon = 1''.70$
	n_1	50	37	35	29	34	54	
	n_2	45	43	42	32	38	40	
	n_3	32	38	34	36	45	22	
	ϵ	5·94	0·07	0·84	0·62	2·01	0·74	

TABLE 5.—*Hayford deflections.*

Sheet No.	Station		Everest's Spheroid Latitude	Everest's Spheroid Longitude	Height in feet	Deflection Everest's Spheroid Meridian	Deflection Everest's Spheroid P. V.	Deflection International Spheroid Meridian	Deflection International Spheroid P. V.	Computed Hayford Deflection Meridian	Computed Hayford Deflection P. V.	Anomaly International Spheroid Meridian	Anomaly International Spheroid P. V.
			° ′ ″	° ′ ″		″	″	″	″	″	″	″	″
38 P	Umarkhel	H.S.	32 25 31·07	71 15 20·79	3036	...	13·7 W	...	10·0 W	...	5·6 W	...	4·4 W
39 D	Dunmb	h.s.	28 15 21·09	68 14 9·96	183	2·8 N	...	1·4 S	...	1·1 N	...	2·5 S	...
39 H	Dāowāla	T.S.	28 20 12·87	69 50 30·68	282	...	12·2 W	...	7·5 W	...	0·7 W	...	6·8 W
40 A	Yūsuf	S.	27 51 8·74	68 26 14·75	215		6·6 W	...	1·2 W	...	0·9 W	...	0·3 W
45 C	Samdari	H.S.	25 48 59·55	72 34 20·84	846	0·0	...	3·3 S	...	0·1 S	...	3·2 S	...
46 A	Dhāmanva	T.S.	23 32 8·40	72 30 56·82	397	5·8 N	...	3·4 N	...	0·8 N	...	2·6 N	...
46 F	Ghorārāo	H.S.	22 52 11·17	73 21 25·45	323	3·1 N	...	0·9 N	...	0·8 N	...	0·1 N	...
46 G	Tarbhān	S	21 0 34·13	73 3 49·79	140	5·8 N	...	4·7 N	...	0·3 S	...	5·0 N	...
47 L	Karabgati	H.S.	16 7 34·87	74 47 56·35	2544	...	6·9 E	...	8·1 E	...	0·7 W	...	8·8 E
53 J	Nāg Tibba	H.S.	30 35 11·57	78 9 9·57	9915	30·5 N	20·8 E	25·1 N	20·2 E	16·7 N	14·2 E	8·4 N	6·0 E
53 J	Banog	H.S.	30 28 36 91	78 0 55·96	7433	32·7 N	23·3 E	27·3 N	22·8 E	15·9 N	...	11·4 N	...
53 J	Mussoorie Dome Observatory	H S.	30 27 40·55	78 4 17·41	6937	36·5 N	25·5 E	31·2 N	25·0 E	14·8*N	...	16·4 N	...
53 J	Jharīpāni	h.s.	30 25 10·05	78 5 20·92	5150	52·5 N	30·8 E	47·2 N	30·2 E	28·9 N	...	18·3 N	...
53 J	Spur Point	h.s.	30 24 37·72	78 5 35·96	3850	53·2 N	28·5 E	47·9 N	27·9 E	28·9 N	...	19·0 N	...
53 J	Rājpur	h.s.	30 23 56·83	78 5 59·89	3500	47·7 N	29·7 E	42·4 N	29·1 E	26·4 N	...	16·0 N	...
72 E	Mahādeo Pokra	H.S.	27 41 31·5	85 31 19·9	7095	37·9 N	...	32·9 N	...	17·5 N	...	15·4 N	...
72 E	Kaulia	H.S.	27 48 58·6	85 14 20·7	7051	33·1 N	...	29·1 N	...	14·6 N	...	14·5 N	...

* Revised Computation.
For the first 9 stations the heights were estimated by Mr P. K. Ghosh, and for the rest by Mr. Abdul Karim.

Chapter II

OBSERVATORIES

BY CAPTAIN G. BOMFORD, R.E.

1. Longitude.—The regular record of the longitude of Dehra Dūn was maintained by bi-weekly observations for local time with the bent transit, and daily reception of the 8^h 01^m G.M.T. Bordeaux and 9^h 55^m G.M.T. Rugby wireless time signals. The time observers were Mr. R. B. Mathur and Computers Jagdish Behari Mathur and Prem Narain. Cloudy weather caused exceptionally long breaks in the time observations in July, and some failures of wireless reception also occurred at this time. The resulting values of the longitude are given in Table 1, in which a single value is given by the association of each observation of local time with the wireless signal received at the least time interval from it, i.e. generally during the preceding afternoon, and occasionally on the following afternoon. Results are given up to July 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 amount given in the " Admiralty Notices to Mariners", and by the demi-definatif corrections of the "Bulletin Horaire". When deducing the longitude from the Bordeaux signals, a correction of + $0^s{\cdot}02$ has been added to the reputed Greenwich time of emission, on account of this having been deduced 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 $20^s{\cdot}91$. The speed of propagation has been taken to be 300,000 km. per second.

Determinations of the value of one division of the level of the bent transit at different times have given very different results. In future it is intended to make monthly determinations of the bubble value, and to take special care to keep the level correction small, and of variable sign. In the past, determinations have been rather infrequent, but a comparison between individual measures of the longitude, and the level correction of the transit observations on which they are based, can serve as a rough basis for a determination of the level correction. All the work done with the bent transit since October 1926 has been analysed in this way, and the following statement shows the results. The value which had been used since Oct. 1926 was 1 division $= 0^s{\cdot}155$.

Value accepted before Sept. 1926	...	$0^s \cdot 130$	
Deduced from observations	1-10-26 to 6-10-26	$0^s \cdot 12$	weakly determined.
„ „ „	7-10-26 to 1-12-26	$0^s \cdot 148$	
Bubble Tester Feb. 1927	...	$0^s \cdot 155$	
Deduced from observations	1-12-26 to May 1927	$0^s \cdot 155$	weakly determined.
„ „ „	Oct. to Nov. 1927	$0^s \cdot 155$	is satisfactory.
„ „ „	Dec. 1927 to Mar. 1928	$0^s \cdot 12$	
Bubble Tester July 1928	...	$0^s \cdot 122$	
Deduced from observations	Oct. 1928 to April 1929	$0^s \cdot 113$	
Bubble Tester Sept. 1929.	...	$0^s \cdot 133$	

It seems clear that the value of one division changed in about November or December 1927. No change has been made in the adopted value of $0^s \cdot 155$ before 1-12-27, but subsequent results up to 31-7-29 have been recomputed with the value $0^s \cdot 120$. The values given in last year's report (Volume IV) include this correction, as delay in printing has made it possible for them to be corrected in the proofs. There can be no doubt that the spirit-level is one of the least satisfactory parts of the transit instrument.

Monthly mean values of the longitude during the current year are given below. The accepted value derived from the International Project of 1926 is $5^h\ 12^m\ 11^s \cdot 79$.

			Bordeaux	Rugby
October 1928	5^h	12^m	$11^s \cdot 72$	$11^s \cdot 75$
November „	„	„	11 ·70	11 ·74
December „	„	„	11 ·75	11 ·73
January 1929	„	„	11 ·80	11 ·84
February „	„	„	11 ·82	11 ·86
March „	„	„	11 ·79	11 ·80
April „	„	„	11 ·82	11 ·85
May „	„	„	11 ·76	11 ·78
June „	„	„	11 ·86	11 ·87
July „	„	„	11 ·81	11 ·76

Chart II shows the variation since 1926.

The curve is rather irregular, but the changes cannot definitely be ascribed to anything but instrumental error.

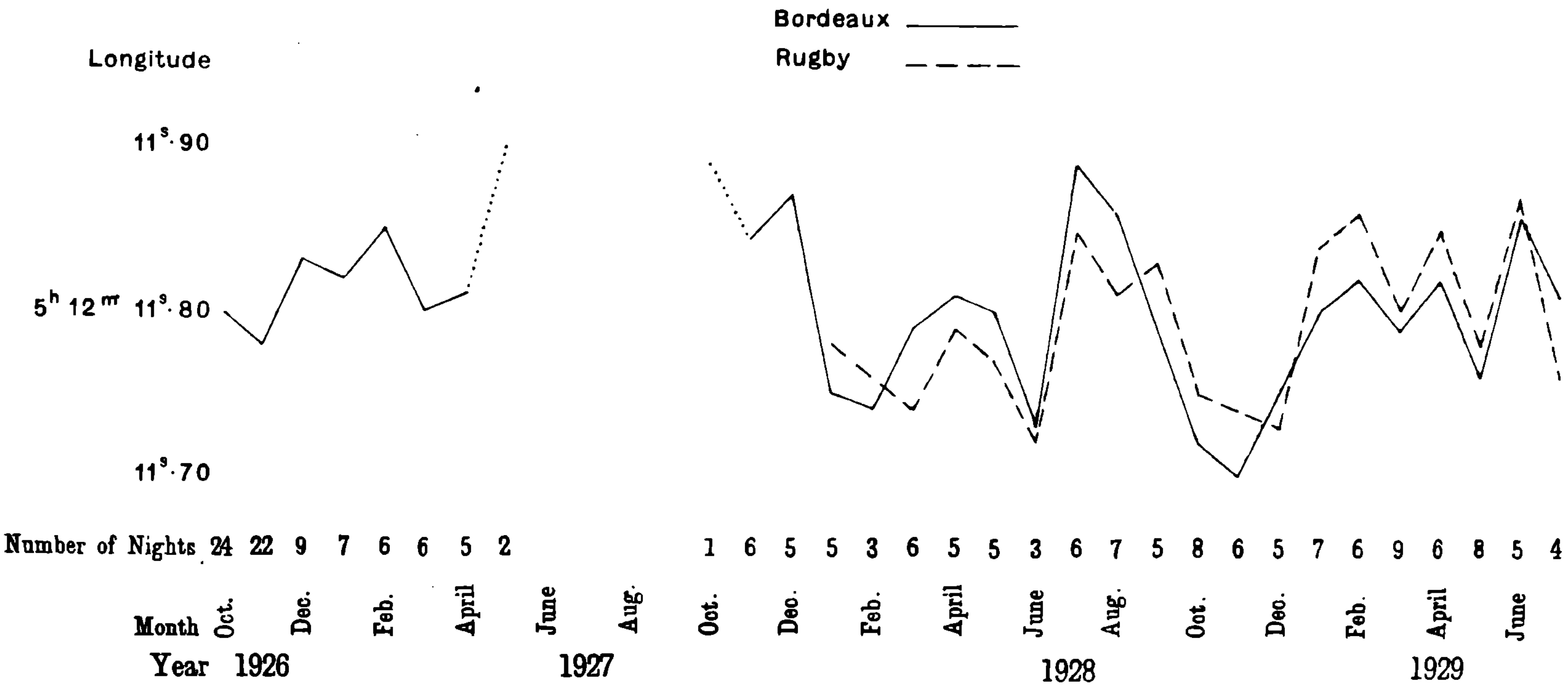
2. **Riefler clock.**—The clock has been running steadily, see Table 2, except between 7th and 18th May when the pressure was adjusted to an unsuitable figure. Leakage of the case has enforced a correction to the pressure every three or four months, but less trouble has been caused on this account than during the previous year. The temperature control has worked regularly, but it has not been possible to prevent the usual rise during the hottest months.

It has hitherto been impossible to use Riefler for the reception of rhythmic signals on account of the irregularity of its seconds. This irregularity has been partly without system, and partly in the form of alternate seconds being slightly too long and too short, the result of dislevelment. While passing through Dehra, Major Glennie (in charge of the pendulum party) was able to correct this

Chart II

LONGITUDE OF DEHRA DŪN

Local time by Transit. Greenwich time from Rugby & Bordeaux. Demi definatif corrections have been applied.



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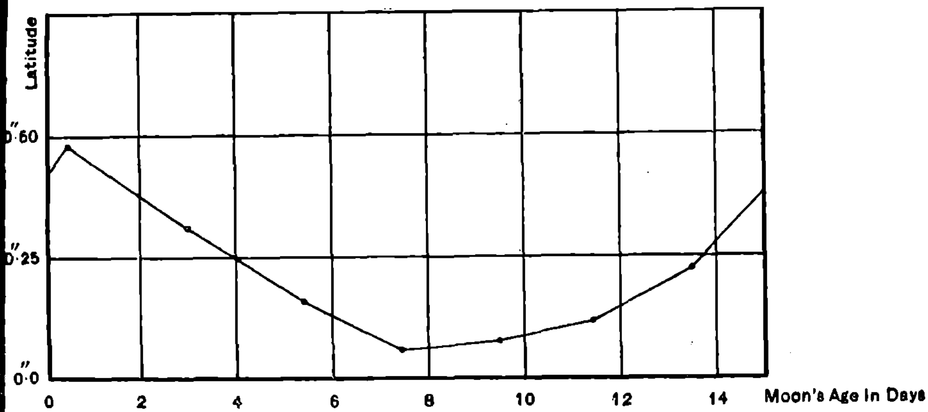
levelling by comparing Riefler against the swinging of his pendulums. It has since been possible to use Riefler for the reception of time signals, without using another clock as an intermediary.

3. **Latitude.**—A few observations of the latitude of Dehra Dūn were made with Zenith Telescope No. 1. The results are given in Table 3 where two previous determinations are given for comparison. They are inadequate for any useful determination of the variation of latitude, but with the exception of the January observation, changes appear to be in fair agreement with figures obtainable by extrapolation from the position of the pole in previous years. It is hoped that these few observations may constitute a preliminary to an adequate series of observations during the current year.



4. **Fortnightly variation of latitude.**—Analysis of the values of the latitude of Dehra Dūn, which were obtained by the prismatic astrolabe in October and November 1926, shows a well marked variation with the moon's age, there being two periods per month. The results on which the analysis is based are given in Geodetic Report Vol. III (1926-27) page 40. The figure shows the result of meaning by every 2 days of the moon's age. The observations made between November 5-6 and 13-14 have been excluded from the mean, as bad weather caused considerable interruption of the programme, and the results were exceptionally irregular. Each point on the diagram represents about 10 series of observations each lasting about two hours, and each giving probable errors of about 0″·3. The probable error of each point in the diagram is thus at least 0″·1, and the smoothness of the curve must partly be due to chance.

Attention has been drawn by A. Gougenheim * to a similar variation at Algiers, also in October and November 1926. The variation shown in the figure is apparently in phase with that at Algiers, but of about one third the amplitude.

Prof. H. T. Stetson † has described a variation of latitude with the moon's hour angle. The Dehra Dūn observations have been

* Comptes Rendus de l' academie des Sciences, July 30, 1928.
† Nature, January 26,1929.

classified in this way, but have not proved sufficient to show his very small variation.

5. **Gravity.**—Dehra Dūn is the base station of the Indian Gravity Survey. Determinations of the values of gravity at Dehra by comparison with European stations, have given extraordinarily variable results (see Chapter IV). It has been suggested that changes in the value of gravity at Dehra are a possible cause of this, and in order to detect any variation with an approximately annual period, a series of 7 observations has been made in the observatory by Mr. R. B. Mathur during the last year. The results are given in Table 4, where the values given are of course based on the assumption that the pendulums have remained unchanged. Pendulum No. 137 has given much less regular results than the other three, and its determinations have been excluded from the mean values. With the exception of August 1929 the mean value is satisfactorily constant, and may be considered to disprove the existence of any annual variation competent to explain the discrepancies in the fundamental determinations. The August 1929 value is rather surprisingly wide, but cannot be held to indicate any periodic variation.

6. **Standards of length.**—A mural base has been constructed in the base line alley. The existing equipment consists of a 24-metre comparator of great accuracy, but which is not well adapted for ordinary rough work, and which can only standardize tapes whose lengths are multiples of 4 metres. There also exists a rough 100 foot standard on the floor of the alley, but it also is rather inconvenient in use, and can deal only with multiples of 10 feet.

The new mural standard has marks at every 10 feet, the first interval being subdivided to every foot. There are also marks at every four metres, measured backwards from the 80 foot mark, with intermediate marks at the first three metres. The 24 metre mark is thus within 3 inches of the one foot mark, and the 100 foot base can readily be brought into terms of the fundamental metre standards. In addition to the row of brass plugs spaced as above, a 100 foot and a 12 metre invar tape are permanently stretched within a couple of inches of the plugs, either of which can be used as a standard. It is expected that these tapes will prove a more permanent standard than the plugs in the wall, but the plugs should prove useful for many purposes. The plugs and standard tapes lie in a narrow trough where they can be submerged in running water. Readings are made by means of movable microscopes which can be put in position as required.

The plugs have now been fixed and the marks cut, but the final standardization has not yet been completed. Arrangements may eventually be made to control the temperature of the running water, but the necessary apparatus has not yet been provided.

7. **Magnetic observations.**—The usual programme of

magnetic observations was carried out, comprising a continuous magnetographic record of declination, horizontal force and vertical force, daily observations of dip, and bi-weekly observations of declination and horizontal force.

The magnetic observatory is usually flooded in August, but this year no flooding occurred.

The mean values of the magnetic elements at Dehra Dūn observatory in 1928 were :—

Declination	E	1° 18′·5
Dip	N	45° 31′·8
Horizontal Force		·32940 C.G.S.
Vertical Force		·33554 C.G.S.

Table 5 gives the monthly mean values of the distribution constants and magnetic moment of Magnet No. 17.

Table 6 shows the monthly mean values of the elements for 1927 and 1928, and the annual changes for that period. The mean hourly deviations from the monthly means are given in Tables 7 to 10. Table 11 gives the classification of the magnetic character of all days of 1928. The 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.

8. Seismograph and meteorological observations.—The Omori seismograph was in operation throughout the year in its new position in the Haig Observatory, where it lies East and West; in the Burrard Observatory it used to be North and South. An exceptionally large number of earthquakes was recorded; many were very slight and indistinct, but the number of large shocks was also exceptional. The increase in small shocks may possibly be due to the better working of the instrument on account of a new pivot bearing having been fitted when it was moved: or it may be a peculiarity of the locality, that an East and West instrument receives more small shocks than one lying North and South. Table 12 gives details of all the earthquakes recorded.

A full programme of meteorological observations has been undertaken since February, the observations being made at 8 a.m. and communicated to the Meteorological Department.

9. Miscellaneous work.—All theodolites, levels and other delicate instruments in the store at Dehra Dūn have been transferred to the care of the Observatory Section, where they can receive a certain amount of attention and inspection before issue, although the accounting work which results is an unwelcome addition to the duties of the officer in charge of the observatory. It will probably be possible to make other arrangements during the current year.

The levels of the levelling party were inspected on their return from the field, and the 10 foot field tapes were standardized.

A small test was made of the Wild telemeter. The test took the form of a traverse of 660 metres, consisting of 6 legs between 70 and 150 metres in length, which closed with an error of 1 in 3,000. The test indicates that the instrument is accurate enough for most traverse purposes, but does not assert that even better work may not be possible after some practice in the use of the instrument.

The Saturday morning course of instruction of about 12 of the geodetic and other computers of the party, was continued during the cold weather of 1928-29. Most of the senior computers of the Computing and Observatory Sections are now conversant with practical triangulation, traversing and levelling. A little instruction in star observations has also been given.

Four Hunter Short Bases (see Vol. IV, Chap. II, para 6) have been constructed and standardized, for the use of the Frontier Circle. One has been lent to H. R. H. the Duke of Spoleto for his expedition to the Kara-koram.

A Tungar rectifier has been installed in the Hennessey Observatory for charging accumulators. Water has been laid on to the Hennessey, Hunter and Burrard Observatories.

TABLE 1.—*Longitude of Dehra Dūn, and its variation from accepted value, as determined from reception of wireless time signals from Bordeaux and Rugby.*

Date Greenwich		Bordeaux		Rugby	
		Longitude in time	Observed value *minus* accepted value*	Longitude in time	Observed value *minus* accepted value*
1928		h m s	s	h m s	s
Oct.	1	5 12 11·80	+ 0·01	5 12 11·93	+ 0·14
	5	11·69	− 0·10	11·63	− 0·16
	9	11·72	− 0·07	11·70	− 0·09
	12	11·83	+ 0·04	11·86	+ 0·07
	16	11·65	− 0·14	11·66	− 0·13
	19	11·67	− 0·12	11·75	− 0·04
	26	11·79	0·00	11·79	0·00
	30	11·62	− 0·17	11·64	− 0·15
Nov.	2	11·66	− 0·13	11·71	− 0·08
	6	11·68	− 0·11	11·72	− 0·07
	9	11·72	− 0·07	11·77	− 0·02
	13	11·63	− 0·16	11·67	− 0·12
	16	11·59	− 0·20	11·61	− 0·18
	21	11·73	− 0·06	11·78	− 0·01
Dec.	3	11·59	− 0·20	11·62	− 0·17
	8	11·67	− 0·12	11·67	− 0·12
	14	11·86	+ 0·07	11·82	+ 0·03
	18	11·79	0·00	11·76	− 0·03
	21	11·82	+ 0·03	11·78	− 0·01
1929					
Jan.	1	11·80	+ 0·01	11·87	+ 0·08
	4	11·76	− 0·03	11·75	− 0·04
	9	11·81	+ 0·02	11·83	+ 0·04
	15	11·82	+ 0·03	11·83	+ 0·04
	19	11·78	− 0·01	11·81	+ 0·02
	22	11·76	− 0·03	11·88	+ 0·09
	28	11·84	+ 0·05	11·90	+ 0·11
Feb.	1	11·81	+ 0·02	11·85	+ 0·06
	6	11·84	+ 0·05	11·86	+ 0·07
	9	11·82	+ 0·03	11·88	+ 0·09
	14	11·83	+ 0·04	11·83	+ 0·04
	19	11·85	+ 0·06	11·86	+ 0·07

(Continued).

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

TABLE 1.—*Longitude of Dehra Dūn, and its variation from accepted value as determined from reception of wireless time signals from Bordeaux and Rugby–(contd.).*

Date Greenwich		Bordeaux				Rugby			
		Longitude in time			Observed value *minus* accepted value*	Longitude in time			Observed value *minus* accepted value*
1929		h	m	s	s	h	m	s	s
Feb.	23	5	12	11·78	− 0·0	5	12	11·87	+ 0·08
March	1			11·81	+ 0·02			11·84	+ 0·05
	2			11·74	− 0·05			11·75	− 0·04
	4			11·76	− 0·03			11·73	− 0·06
	7			11·79	0·00			11·82	+ 0·03
	13			11·75	− 0·04			11·86	+ 0·07
	19			11·84	+ 0·05			11·84	+ 0·05
	22			11·84	+ 0·05			11·81	+ 0·02
	27			11·81	+ 0·02			11·73	− 0·06
	31			11·81	+ 0·02			11·83	+ 0·04
April	8			11·81	+ 0·02			11·83	+ 0·04
	10			11·70	− 0·09			11·77	− 0·02
	15			11·92	+ 0·13			11·94	+ 0·15
	19			11·88	+ 0·09			11·91	+ 0·12
	25			11·84	+ 0·05			11·86	+ 0·07
	29			11·77	− 0·02			11·77	− 0·02
May	2			11·58	− 0·21			11·72	− 0·07
	8			11·57	− 0·22			11·71	− 0·08
	10			11·85	+ 0·06			11·85	+ 0·06
	14			11·88	+ 0·09			11·83	+ 0·04
	20			11·70	− 0·09			11·83	+ 0·04
	26			11·82	+ 0·03			11·75	− 0·04
	29			11·83	+ 0·04			11·77	− 0·02
	31			11·86	+ 0·07			11·81	+ 0·02
June	6			11·86	+ 0·07			11·91	+ 0·12
	14			11·87	+ 0·08			11·84	+ 0·05
	22			11·90	+ 0·11			11·77	− 0·02
	26			11·77	− 0·02			11·90	+ 0·11
	29			11·91	+ 0·12			11·91	+ 0·12
July	1			11·84	+ 0·05			11·80	+ 0·01
	3			11·81	+ 0·02			11·76	− 0·03
	9			11·77	− 0·02			11·79	0·00
	29			.	...			11·68	− 0·11

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

TABLE 2.—*Temperature and pressure of Riefler clock No. 450, and its error and rate, by bent transit instrument, at 20 hours Indian standard time, 1928-29.*

ɔate	Error	Observers	During preceding period			Remarks
			Rate* per day	Pressure	Temperature	
1928	m s		s	mm	C	
;. 1	−1 02·89	P.N.	− 0·16	586	28·0	
5	03·10	,,	− 0·05	586	27·7	
9	03·71	,,	− 0·16	586	27·4	
12	04·15	,,	− 0·14	586	27·0	
16	04·19	,,	− 0·01	585	26·8	
19	04·48	,,	− 0·10	584	26·7	
26	05·07	,,	− 0·09	584	26·3	Pressure reduced to 556 mm. at 3 p.m. on 28th Oct. 1928.
30	04·58	,,	+ 0·12	566	26·7	
r. 2	03·97	,,	+ 0·20	560	26·5	
6	03·30	,,	+ 0·17	560	26·5	
9	02·80	,,	+ 0·17	560	26·6	
13	02·10	,,	+ 0·18	560	26·5	
16	01·82	,,	+ 0·09	560	26·7	
21	01·30	R.B.M.	+ 0·10	560	26·6	
;. 3	00·42	,,	+ 0·08	561	26·5	
8	00·53	J.B.	− 0·02	562	26·6	
14	00·50	,,	− 0·01	561	25·8	
18	00·08	,,	+ 0·11	560	25·6	
21	00·07	,,	+ 0·00	565	26·6	
929						
. 1	0 57·64	,,	+ 0·22	564	26·6	
4	56·74	,,	+ 0·29	564	26·7	
9	55·48	,,	+ 0·26	564	25·9	
15	53·86	,,	+ 0·27	565	26·4	
19	52·84	,,	+ 0·24	568	26·3	
22	52·43	,,	+ 0·14	572	26·2	
28	51·99	,,	+ 0·08	577	26·7	Pressure reduced to 558 mm. at 7 p.m. on 30th January 1929.
). 1	51·39	,,	+ 0·15	572	26·6	
6	50·25	,,	+ 0·23	566	26·8	
9	49·78	,,	+ 0·15	570	26·6	
14	49·15	,,	+ 0·13	573	26·4	
19	48·79	,,	+ 0·07	577	25·9	
23	48·75	,,	+ 0·01	582	26·5	
rch 1	49·10	,,	− 0·06	586	27·0	
2	49·10	R.B.M.	0·00	588	27·0	
4	49·22	,,	− 0·07	589	26·2	
7	49·46	J.B.	− 0·08	592	26·6	
13	49·12	,,	+ 0·06	595	26·9	Clock levelled.
19	47·27	,,	+ 0·31	596	25·9	
22	46·41	,,	+ 0·28	600	27·1	
27	44·94	,,	+ 0·29	600	26·4	

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

(*Continued*)

TABLE 2.—*Temperature and pressure of Riefler clock No. 450, and its error and rate, by bent transit instrument, at 20 hours Indian standard time, 1928-29–(contd.).*

Date	Error	Observers	During preceding period: Rate* per day	Pressure	Temperature	Remarks
1929	m s		s	mm	°C	
March 31	−0 43·94	J. B.	+ 0·25	604	26·8	
April 8	42·24	,,	+ 0·21	605	26·7	
10	41·72	R. B. M.	+ 0·26	608	26·5	
15	40·93	J. B.	+ 0·16	608	26·5	
19	40·19	,,	+ 0·19	610	26·5	
25	39·34	,,	+ 0·14	614	26·9	
29	38·88	,,	+ 0·12	616	26·7	
May 2	38·65	,,	+ 0·07	618	27·1	Pressure reduced to 568 mm. at 6 a.m. on 7th May 1929.
8	37·28	,,	+ 0·23	568	28·4	
10	35·94	,,	+ 0·67	570	29·0	
14	33·02	,,	+ 0·73	572	29·2	Pressure increased to 620 mm. at 6 a.m. on 18th May 1929.
20	30·33	R. B. M.	+ 0·44	597	29·5	
26	30·05	,,	+ 0·04	624	30·0	
29	30·03	J. B.	+ 0·01	627	30·5	
31	30·05	,,	− 0·01	629	31·2	
June 6	29·93	,,	+ 0·02	633	32·1	
14	29·66	,,	+ 0·04	635	32·5	
22	29·74	,,	− 0·01	634	31·5	
26	29·92	,,	− 0·05	634	30·9	
29	29·97	,,	− 0·01	633	30·6	
July 1	29·86	,,	+ 0·04	634	30·5	
3	29·70	,,	+ 0·08	634	30·6	
9	29·48	,,	+ 0·03	633	30·3	
29	28·83	,,	+ 0·03	633	30·0	
Aug. 2	28·84	,,	0·00	633	28·9	
17	28·15	,,	+ 0·04	632	28·1	
19	28·30	,,	− 0·08	631	27·3	
21	28·37	,,	− 0·03	631	27·5	
28	28·38	,,	0·00	631	27·8	
Sept. 3	28·46	,,	− 0·02	632	28·0	During this month pressure was gradually increasing owing to leakage.
5	28·54	,,	− 0·03	633	28·1	
11	28·78	R. B. M.	− 0·04	634	28·3	
18	29·91	,,	− 0·16	643	28·4	Pressure reduced to 632 mm. at 3 p.m. on 18th Sept. 1929.
22	30·41	,,	− 0·13	643	28·6	Pressure reduced to 628 mm. at 9·30 a.m. on 24th September 1929.
27	31·21	H. C. B.	− 0·15	639	28·5	

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

TABLE 3.—*Latitude observations, Dehra Dūn.*

Date of observation	No. of pairs observed	Mean date	Probable error	Observed latitude	Observed latitude *minus* accepted latitude
			"	° ′ "	"
Dec. 1904 & Mar. 1905	16	1905·05	± 0·08	30 18 51·80	0·00
Oct.-Nov. 1926	...*	1926·83	± 0·03	30 18 52·03	+ 0·23
5 10 28	3½	1928·82	± 0·20	30 18 52·24	+ 0·44
9 ,, ,,	1				
14 ,, ,,	2½				
26 ,, ,,	10				
5 11 28	7				
16 ,, ,,	7				
19 ,, ,,	7				
9 1 29	11	1929·03	± 0·19	30 18 52·51	+ 0·71
11 ,, ,,	12				
16 2 29	11	1929·13	± 0·18	30 18 51·92	+ 0·12
17 ,, ,,	13				
15 4 29	6	1929·29	± 0·16	30 18 51·78	− 0·02
16 ,, ,,	7				
19 5 29	8½	1929·38	± 0·12	30 18 51·65	− 0·15
20 ,, ,,	8½				

* Astrolabe, about 20 stars in each of 92 series of observation.
NOTE:—The latitude given is that of the Haig Observatory.

TABLE 4.—*Value of g at Dehra Dūn, as derived from observations with the brass pendulums.*

Month	Pendulum				Mean of Nos. 138, 139 and 140
	137	138	139	140	
1928	*Dynes*	*Dynes*	*Dynes*	*Dynes*	*Dynes*
August 29th ..	979·084	979·076	979·085	979·072	979·078
November 5th ...	·083	·074	·075	·073	·074
November 25th	·337*	·074	·083	·076	·078
1929					
January 7th ...	·081	·082	·079	·073	·078
April 25th ...	·094	·076	·079	·073	·076
May 30th ...	·078	·077	·081	·072	·077
August 29th ...	·069	·066	·073	·073	·071

* Source of error unexplained.

TABLE 5.—*Mean values of the constants of Magnet No. 17 in 1928.*

Month	Declination constants: Mean magnetic collimation	H. F. Constants: Distribution factors: $P_{1\cdot2}$	$P_{2\cdot3}$	Accepted value of $\log\left(1+\frac{P}{r^2}+\frac{Q}{r^4}\right)^{-1}$	Mean values of "m": Monthly means	Accepted "m"
	′ ″	cm²	cm²		C. G. S.	
January ...	− 6 21	5·85	6·85	$\overline{1}$·99385 throughout	806·39	806·18 throughout
February ...	− 6 21	5·76	6·98		·32	
March ...	− 6 16	5·96	6·84		·35	
April ...	− 6 16	5·79	6·96		·25	
May ...	− 6 17	5·78	6·99		·14	
June ...	− 6 15	5·84	6·97		·11	
July ...	− 6 22	5·81	7·00		·08	
August ...	− 6 21	5·70	7·02		·15	
September ...	− 6 21	5·74	7·03		·13	
October ...	− 6 21	5·86	7·09		·16	
November ...	− 6 20	5·85	7·04		·23	
December ...	− 6 22	5·81	7·09		·28	

TABLE 6.—*Monthly mean values of the Magnetic elements, and their annual changes. Dehra Dūn, 1927-28.*

Month	Horizontal force ·32,000 C.G.S. +			Declination E. 1° +			Dip N. 45° +			Vertical force ·33,000 C.G.S. +		
	1927	1928	Annual change	1927	1928	Annual change	1927	1928	Annual change	1927	1928	Annual change
	γ*	γ*	γ*	′	′	′	′	′	′	γ*	γ*	γ*
January ...	919	958	+ 39	24·1	19·9	− 4·2	27·6	29·1	+ 1·5	452	521	+ 69
February ...	931	938	+ 7	23·7	19·5	− 4·2	28·2	30·8	+ 2·6	476	533	+ 57
March	928	943	+ 15	23·6	19·3	− 4·3	28·5	31·0	+ 2·5	479	543	+ 64
April ...	929	942	+ 13	22·6	19·0	− 3·6	27·6	31·1	+ 3·5	463	542	+ 79
May ...	934	956	+ 22	22·5	18·6	− 3·9	28·0	30·6	+ 2·6	474	547	+ 73
June ...	949	940	− 9	22·0	18·6	− 3·4	28·0	31·9	+ 3·9	491	557	+ 66
July ...	946	931	− 15	21·6	18·6	− 3·0	29·3	32·5	+ 3·2	514	559	+ 45
August ...	931	933	+ 2	21·2	18·1	− 3·1	30·3	32·4	+ 2·1	518	559	+ 41
September ...	932	931	− 1	21·1	18·1	− 3·0	30·5	33·2	+ 2·7	520	574	+ 54
October ...	914	940	+ 26	21·4	17·7	− 3·7	30·5	33·0	+ 2·5	502	577	+ 75
November ...	930	929	− 1	20·8	17·4	− 3·4	30·3	32·9	+ 2·6	515	564	+ 49
December ...	925	935	+ 10	20·6	17·3	− 3·3	31·1	33·2	+ 2·1	526	577	+ 51
Means ...	931	940	+ 9	22·1	18·5	− 3·6	29·2	31·8	+ 2·7	494	554	+ 60

* γ = ·00001 C.G.S.

TABLE 7.—*Declination at Dehra Dūn in 1928*, (determined from 5 selected quiet days in each month).

Month	Monthly† mean values	Hourly mean *minus* monthly mean																								
		0	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	0
	$E_1°+$	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
Jan.	19·9	0·0	+0·3	0·0	−0·1	−0·2	−0·4	−0·6	−0·4	+0·6	+1·9	**+2·3**	+0·3	−0·9	**−1·2**	−1·1	−0·9	−0·3	−0·1	−0·1	0·0	+0·1	0·0	0·0	0·0	0·0
Feb.	19·5	+0·3	+0·5	+0·6	+0·5	+0·4	+0·1	0·0	−0·3	+0·3	+0·9	**+1·1**	+0·6	−0·2	−0·7	**−0·9**	−0·7	−0·5	−0·4	−0·4	−0·2	−0·3	−0·1	+0·1	+0·4	+0·3
Mar.	19·3	+0·2	+0·2	+0·1	0·0	+0·1	−0·1	0·0	+0·8	+2·4	**+3·2**	+2·7	+1·3	−1·1	−2·4	**−2·7**	−1·9	−0·7	−0·3	−0·1	−0·3	−0·3	−0·3	−0·2	−0·1	0·0
Oct.	17·7	+0·5	+0·6	+0·4	+0·3	+0·2	+0·1	+0·6	+2·0	**+2·4**	+1·9	+0·7	−1·3	−2·5	**−2·8**	−1·8	−0·6	−0·0	−0·1	−0·5	−0·3	−0·1	0·0	−0·1	+0·1	+0·3
Nov.	17·4	+0·3	+0·5	+0·3	+0·5	+0·3	+0·2	+0·3	+0·9	**+1·3**	+1·3	+0·4	−0·3	**−1·3**	−1·1	−0·2	−0·4	−0·4	−0·7	−0·3	−0·2	−0·1	−0·1	−0·1	0·0	0·0
Dec.	17·3	+0·3	+0·3	+0·2	0·0	−0·1	−0·3	−0·3	−0·1	+0·7	**+1·3**	+0·9	+0·4	−0·5	**−1·1**	−0·7	−0·7	−0·5	−0·4	−0·1	0·0	0·0	−0·1	0·0	0·0	0·0
Winter Means	18·5	+0·3	+0·4	+0·3	+0·2	+0·1	−0·1	0·0	+0·5	+1·3	**+1·8**	+1·4	+0·2	−1·1	**−1·6**	−1·2	−0·9	−0·4	−0·3	−0·3	−0·2	−0·1	−0·1	0·0	+0·1	+0·1
April	19·0	+0·1	+0·2	+0·2	0·0	−0·1	0·0	+0·9	+2·7	+4·2	**+4·6**	+3·0	+0·2	−2·2	**−3·5**	−3·4	−2·4	−1·4	−0·5	−0·0	−0·4	−0·5	−0·5	−0·3	−0·2	0·0
May	18·6	+0·1	+0·1	+0·3	+0·4	+0·3	+0·6	−1·9	+3·8	**+4·5**	+3·8	+1·9	−0·7	−2·4	**−3·6**	−3·0	−2·4	−1·6	−1·0	−0·4	−0·3	−0·5	−0·4	−0·4	−0·2	−0·1
June	18·6	+0·1	+0·4	+0·6	+0·6	+0·6	+0·6	+2·0	+2·9	**+2·9**	+2·3	+1·6	−0·1	−1·4	−2·4	**−2·5**	−2·5	−2·3	−1·4	−0·3	−0·1	−0·5	−0·5	−0·4	−0·4	−0·1
July	18·6	−0·1	0·0	+0·3	+0·1	+0·4	+0·7	+2·3	+3·4	**+4·1**	+3·3	+2·0	0·0	−1·7	−2·8	**−3·0**	−2·4	−1·5	−0·9	−0·7	−0·9	−0·9	−0·8	−0·7	−0·5	−0·3
Aug.	18·1	+0·1	+0·3	+0·4	+0·4	+0·6	+0·9	+2·3	**+3·3**	+3·2	+1·9	+0·3	−1·4	−2·8	**−3·0**	−2·7	−1·6	−0·9	−0·4	+0·2	−0·4	−0·5	−0·3	−0·4	−0·2	0·0
Sept.	18·1	+0·7	+0·4	+0·3	+0·5	+0·4	+0·6	+1·6	+3·1	**+4·0**	+2·8	+0·7	−1·4	−3·1	**−3·8**	−3·3	−1·6	−0·3	+0·3	−0·2	−0·4	−0·4	−0·3	−0·1	+0·2	+0·4
Summer Means	18·5	+0·2	+0·2	+0·4	+0·3	+0·4	+0·6	+1·8	+3·2	**+3·8**	+3·1	+1·6	−0·6	−2·3	**−3·2**	−3·0	−2·2	−1·3	−0·7	−0·2	−0·4	−0·6	−0·5	−0·4	−0·2	0·0

† Obtained from the mean of all hours of the 5 selected quiet days in each month.

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

TABLE 8.—*Horizontal force at Dehra Dūn in 1928*, (determined from 5 selected quiet days in each month).

Month	Monthly† mean values	Hourly mean *minus* monthly mean																								
		0	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	0
	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
Jan.	32958	− 2	− 2	− 1	− 1	− 2	− 1	+ 2	+ 5	+ 4	− 1	− 7	− 2	+ 3	+ **5**	+ **5**	+ 4	+ 1	0	− 1	− 3	− 3	− 4	− 2	− 2	− 2
Feb.	938	− 7	− 4	− 7	− 5	− 6	− 4	− 3	+ 3	+ 6	+ 11	+ 15	+ **16**	+ 15	+ 12	+ 5	− 1	− 5	− 7	− 6	− 4	− 5	− 8	− **9**	− 9	− 4
Mar.	943	− 6	− 7	− 8	− 7	− 7	− 5	− 5	− 4	− 4	− 2	+ 4	+ 13	+ 18	+ **18**	+ 17	+ 11	+ 2	− 2	− 2	+ 4	− 5	− 6	− 5	− 5	− 4
Oct.	940	− 7	− **10**	− 8	− 6	− 6	− 6	− 6	− 6	− 9	− 3	+ 8	+ 16	+ 19	+ **22**	+ 16	+ 8	+ 1	− 5	− 4	− 1	− 4	− 5	− 7	− 4	− 3
Nov.	92[illegible]	− **11**	− 7	− 10	− 8	− 6	− 6	− 5	− 4	− 2	0	+ 4	+ 10	+ 14	+ **14**	+ 7	+ 5	+ 2	− 1	0	0	− 2	− 3	− 2	− 1	− 1
Dec.	935	− 2	− **9**	− 8	− 4	− 3	− 2	0	+ 3	+ 6	+ 5	+ 4	+ **6**	+ 6	+ 2	+ 1	+ 1	0	− 1	0	+ 1	− 4	− 5	− 2	− 1	− 1
Winter Means	32941	− 6	− 7	− 7	− 5	− 5	− 4	− 3	− 1	0	+ 2	+ 5	+ 10	+ **13**	+ 12	+ 9	+ 5	0	− 3	− 2	− 1	− 4	− 5	− 5	− 4	− 3
April	32942	− 9	− 9	− 9	− 9	− 7	− 9	− 7	− 9	− 7	0	+ 4	+ 19	+ 24	+ **26**	+ 21	+ 15	+ 8	+ 2	− 5	− 9	− **10**	− 9	− 8	− 7	− 7
May	956	− 3	− 4	− 4	− 4	− 2	− 4	− 3	− 4	− 5	− 5	+ 1	+ 7	+ 13	+ **17**	+ 16	+ 9	+ 6	+ 2	− 4	− 8	− 8	− 7	− 5	− 3	− 3
June	940	− **7**	− 6	− 6	− 6	− 6	− 5	− 2	− 4	− 4	− 1	+ 5	+ 10	+ 12	+ **12**	+ 6	+ 7	+ 4	0	− 3	− 2	− 2	+ 1	+ 1	+ 2	0
July	931	− 5	− 3	− 3	− 3	− 4	− 2	− 1	− 4	− **9**	− 6	− 2	+ 2	+ 6	+ 12	+ **17**	+ 11	+ 4	0	− 4	− 2	0	− 1	0	+ 3	+ 4
Aug.	933	− 6	− 6	− 6	− 4	− 5	− 4	− 3	− 6	− **11**	− 8	− 2	+ 5	+ 12	+ **16**	+ 16	+ 11	+ 5	− 2	− 2	− 2	0	0	− 1	− 1	0
Sept.	931	− 9	− 6	− 4	− 6	− 5	− 3	− 5	− 8	− 12	− **15**	− 11	− 3	+ 3	+ 13	+ **16**	+ 15	+ 11	+ 6	+ 6	+ 7	+ 7	+ 5	+ 5	+ 4	+ 9
Summer Means	32939	− 7	− 6	− 5	− 5	− 5	− 5	− 4	− 6	− 8	− 6	− 1	+ 7	+ 12	+ **16**	+ 15	+ 11	+ 6	+ 1	− 2	− 3	− 2	− 2	− 1	0	+ 1

† Obtained from the mean of all hours of the 5 selected quiet days in each month.

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

γ = 0·00001 C. G. S.

TABLE 9.—*Vertical force at Dehra Dūn in 1928*, (determined from 5 selected quiet days in each month).

Month	Monthly† mean values	Hourly mean *minus* monthly mean																								
		0	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	0
	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
Jan.	33521	+ 4	+ 3	+ 4	+ 3	+ 2	+ 3	+ 4	+ 3	+ 5	+ **5**	− 1	−10	**−11**	− 9	− 8	− 2	+ 1	+ 1	+ 2	+ 2	+ 1	+ 1	+ 1	+ 1	0
Feb	533	0	0	0	0	0	− 1	− 1	0	+ 2	+ 2	− 3	− 4	− 6	− **7**	− 6	− 4	− 2	0	+ 1	+ 3	+ 4	+ 3	+ 4	+ 4	+ **5**
Mar.	543	0	+ 1	+ 1	+ 1	+ 1	0	0	+ 5	+ 6	+ 1	− 8	− 6	**−13**	−12	− 8	− 2	+ **3**	+ 4	+ 3	+ 3	+ 4	+ 6	+ 6	+ 6	+ **6**
Oct.	577	+ 5	+ 4	+ 4	+ 4	+ 4	+ 4	+ 5	+ **8**	+ 5	0	− 7	−17	**−18**	−13	− 5	− 1	+ 1	0	+ 1	+ 4	+ 4	+ 5	+ 6	+ 6	+ 6
Nov.	564	+ 3	+ 3	+ 2	+ 2	+ 2	+ 2	+ 2	+ 3	+ **4**	− 1	− 4	− **6**	− 5	− 4	− 3	− 1	− 1	− 1	+ 2	+ 1	+ 1	+ 1	+ 1	+ 1	+ 1
Dec.	577	+ 3	+ 2	+ 3	+ 3	+ 2	+ 2	+ 2	+ 4	+ **6**	+ 6	0	− 2	− 5	− **5**	− 4	− 2	− 1	+ 1	+ 2	0	− 1	− 1	− 1	− 1	− 2
Winter Means	33553	+ 3	+ 2	+ 2	+ 2	+ 2	+ 2	+ 2	+ 4	+ **5**	+ 2	− 4	− 8	**−10**	− 8	− 6	− 2	0	+ 1	+ 2	+ 2	+ 2	+ 3	+ 3	+ 3	+ 3
April	33542	+ 7	+ 7	+ 7	+ 6	+ 7	+ 7	+11	+13	+ **14**	+ 6	− 6	−15	**−20**	−18	−11	− 6	− 2	0	− 2	− 3	− 2	0	0	0	− 1
May	547	+ 7	+ 6	+ 6	+ 5	+ 6	+ 7	+10	+ **10**	+ 4	− 5	−15	**−18**	−16	−14	− 8	− 4	0	+ 1	+ 2	+ 0	+ 1	+ 3	+ 4	+ 4	+ 4
June	557	+ 3	+ 3	+ 4	+ 3	+ 4	+ 5	+ **10**	+ 8	+ 4	+ 1	− 4	−13	−15	**−15**	−12	− 8	− 3	0	+ 2	+ 3	+ 3	+ 5	+ 5	+ 6	+ 6
July	559	+ 2	+ 3	+ 3	+ 3	+ 2	+ 5	+ **8**	+ 7	+ 4	+ 2	− 6	−13	**−17**	−13	− 9	− 4	+ 1	+ 2	+ 3	+ 3	+ 4	+ 5	+ 6	+ 7	+ 7
Aug.	559	+ 9	+ 9	+10	+10	+10	+10	+ **16**	+13	+ 8	+ 2	− 5	**−16**	−15	−13	− 9	− 9	+ 6	− 4	− 4	− 5	− 4	− 4	− 5	− 5	− 5
Sept.	574	+ 5	+ 4	+ 4	+ 3	+ 4	+ 4	+ 7	+ **10**	+ 7	− 2	−12	**−17**	−17	−12	− 5	+ 2	+ 4	+ 3	+ 2	+ 3	+ 4	+ 3	+ 4	+ 4	+ 5
Summer Means	33556	+ 6	+ 5	+ 6	+ 5	+ 6	+ 6	+ **10**	+10	+ 7	+ 1	− 8	−15	**−17**	−14	− 9	− 5	− 1	0	+ 1	0	+ 1	+ 2	+ 2	+ 3	+ 3

† Obtained from the mean of all hours of the 5 selected quiet days in each month.

NOTE—The mean vertical force for any hour may be obtained by applying the hourly deviation for that hour with the sign given, to the mean monthly value.
Figures in thick type indicate the maximum and minimum values of the hourly deviation.
$\gamma = 0{\cdot}00001$ C. G. S.

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TABLE 10.—*Dip at Dehra Dūn in 1928*, (determined from 5 selected quiet days in each month).

Month	Monthly† mean values	0	1	2	3	4	5	6	7	8	9	10	11	Noon	13	14	15	16	17	18	19	20	21	22	23	0
		Hourly mean *minus* monthly mean																								
	N45° + ′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
Jan	29·1	+0·3	+0·3	+0·3	+0·2	+0·2	+0·2	+0·1	−0·1	+0·1	+0·3	**+0·3**	−0·4	−0·7	**−0·7**	−0·6	−0·3	−0·0	+0·1	+0·2	+0·3	+0·2	+0·3	+0·2	+0·2	+0·1
Feb.	30·8	+0·3	+0·2	+0·3	+0·2	+0·3	+0·1	+0·1	−0·2	−0·2	−0·5	−1·0	−1·1	**−1·1**	−1·0	−0·6	−0·2	+0·1	+0·3	+0·3	+0·3	+0·4	+0·6	**+0·7**	+0·7	+0·4
Mar	31·0	+0·3	+0·4	+0·5	+0·4	+0·4	+0·3	+0·3	+0·5	+0·5	+0·2	−0·6	−1·0	**−1·6**	−1·5	−1·3	−0·6	+0·1	+0·3	+0·3	0·0	+0·5	**+0·7**	+0·6	+0·6	+0·5
Oct.	33·0	+0·6	**+0·7**	+0·6	+0·4	+0·4	+0·4	+0·5	+0·7	+0·7	+0·1	−0·8	−1·8	**−2·0**	−1·9	−1·2	−0·5	−0·1	+0·2	+0·2	+0·2	+0·3	+0·4	+0·6	+0·4	+0·4
Nov.	32·9	**+0·7**	+0·5	+0·6	+0·5	+0·4	+0·4	+0·3	+0·3	+0·2	−0·1	−0·5	−0·9	**−1·0**	−1·0	−0·6	−0·4	−0·2	−0·1	0·0	0·0	+0·1	+0·1	+0·1	0·0	0·0
Dec.	33·2	+0·2	**+0·6**	+0·6	+0·4	+0·2	+0·2	+0·1	0·0	0·0	0·0	−0·2	−0·4	**−0·6**	−0·4	−0·3	−0·2	−0·1	+0·1	+0·1	−0·1	+0·1	+0·2	0·0	0·0	−0·1
Winter Means	31·7	+0·4	+0·5	**+0·5**	+0·4	+0·3	+0·3	+0·2	+0·2	+0·2	0·0	−0·5	−0·9	**−1·2**	−1·1	−0·8	−0·4	0·0	+0·2	+0·2	+0·1	+0·3	+0·4	+0·4	+0·3	+0·2
April	31·1	+0·8	+0·8	+0·8	+0·7	+0·7	+0·8	+0·9	**+1·1**	+1·0	+0·2	−0·6	−1·8	−2·3	**−2·3**	−1·7	−1·2	−0·6	−0·2	+0·1	+0·2	+0·4	+0·4	+0·3	+0·3	+0·2
May	30·6	+0·5	+0·5	+0·5	+0·4	+0·4	+0·5	+0·6	**+0·7**	+0·4	0·0	−0·9	−1·3	−1·5	**−1·6**	−1·3	−0·7	−0·4	−0·1	+0·3	+0·4	+0·4	+0·5	+0·4	+0·3	+0·3
June	31·9	+0·5	+0·5	+0·5	+0·5	+0·5	+0·5	+0·6	**+0·6**	+0·4	+0·1	−0·5	−1·2	**−1·4**	−1·4	−1·3	−0·8	−0·4	0·0	+0·3	+0·3	+0·3	+0·2	+0·2	+0·2	+0·3
July	32·5	+0·3	+0·3	+0·3	+0·3	+0·3	+0·3	+0·4	+0·5	**+0·7**	+0·4	−0·2	−0·8	−1·2	−1·3	**1·4**	−0·8	−0·2	+0·1	+0·3	+0·2	+0·2	+0·3	+0·3	+0·2	+0·1
Aug.	32·4	+0·7	+0·7	+0·8	+0·7	+0·7	+0·7	+0·9	+1·0	**+1·0**	+0·5	−0·2	−1·1	−1·4	**−1·5**	−1·3	−1·1	−0·6	−0·1	−0·1	−0·2	−0·2	−0·2	−0·2	−0·2	−0·3
Sept.	33·2	+0·8	+0·6	+0·5	+0·5	+0·5	+0·4	+0·7	+1·0	**+1·0**	+0·7	0·0	−0·7	−1·0	**−1·2**	−1·0	−0·6	−0·3	−0·1	−0·2	−0·2	−0·1	−0·1	0·0	0·0	−0·2
Summer Means	32·0	+0·6	+0·6	+0·6	+0·5	+0·5	+0·5	+0·7	**+0·8**	+0·8	+0·3	−0·4	−1·2	−1·5	**−1·6**	−1·3	−0·9	−0·4	−0·1	+0·1	+0·1	+0·2	+0·2	+0·2	+0·1	+0·1

† Obtained from the mean of all hours of the 5 selected quiet days in each month.

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

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

C = Calm. S = Slight. M = Moderate. G = Great. VG = Very great. (C) or (S) = Selected quiet day. * = H.F. & Declination trace partly lost.

TABLE 12.—*Earthquakes recorded at Dehra Dūn during 1928-29.*

No.	Date	Indian standard time					Intensity of record	Distance	Remarks
		1st P.T.	2nd P.T.	Long wave	Maximum	Finish			
	1928	*h m s*	*h m s*	*h m s*	*h m*	*h m*		miles	
1	Oct. 5	0 01 00†	...	...	0 24	0 46	slight	...	
2	„ 9	8 53 00	...	9 05 00†	9 [illegible]8	11 23	moderate	2900	
3	„ 15	19 51 50	...	19 54 50	19 56	21 45	severe	600	
4	Nov. 6	...	...	...	10 36	11 31	slight	...	Beginning missed while changing drum.
5	„ 12	...	...	...	4 45	5 16	slight	...	
6	„ 14	10 04 40	10 05 40†	10 06 40	10 07	10 25	moderate	400	
7	„ 21	2 25 00	...	2 59 00†	3 31	4 30	slight	8900	
8	„ 22	14 27 00†	14 36 00†	14 46 40	14 59	15 48	slight	4900	
9	„ 28	16 22 40	16 30 40	16 42 40	16 51	18 12	slight	4400	
10	Dec. 1	...	...	10 32 10	11 08	12 10	severe	.	do
11	„ 2	..	...	...	11 16	12 24	slight	...	Continuous slight movement during night of 1st and 2nd December.
12	„ 7	14 55 10	15 03 40	15 15 00†	15 25	16 22	slight	4600	
13	„ 10	10 10 50†	10 16 20	10 21 20	10 24	10 47	slight	2400	
14	„ 12	6 59 00	...	7 00 00	7 00	7 27	slight	200	
15	„ 13	2 05 00†	...	...	3 12	3 57	slight	...	
16	„ 14	6 01 00	...	6 03 20	6 06	8 25	slight	40	
17	„ 19	17 16 00	17 23 00	17 27 10	17 33	20 05	moderate	3000	
18	„ 28	19 58 30	20 05 30	20 12 00†	20 16	21 01	slight	3000	
	1929								
19	Jan. 8	13 04 00†	...	13 26 00†	13 28	14 10	slight	5200	
20	„ 13	5 42 40	5 50 40	6 01 00	6 09	9 00	moderate	4000	
21	„ 14	15 15 40	...	15 16 20	15 16	15 43	slight	200	
22	„ 16	13 43 40	13 52 00†	14 00 40	14 07	15 21	slight	4300	
23	„ 17	17 44 00†	17 58 00†	18 15 00†	18 29	19 42	slight	8300	
24	„ 25	2 27 00†	2 41 00†	3 09 50	3 25	6 16	great	11500	
25	Feb. 1	22 46 20	22 47 00	22 47 40	22 48	4 52	great	260	N. W. Himālaya
26	„ 2	.	...	...	6 19	9 18	slight	.	
27	„ 14	20 21 00†	...	...	20 38	21 10	slight	...	
28	„ 23	2 32 00†	2 44 00†	3 04 00†	3 14	4 00	slight	7900	
29	„ 26	14 43 00	14 53 00	15 03 20	15 24	17 10	slight	5200	
30	Mar. 7	7 16 30	7 26 40	7 44 30	7 28	8 17	slight	6300	Revised values. Aleutian Islands, Behring Sea.

† Recognized with difficulty.

(*Continued*).

TABLE 12.—*Earthquakes recorded at Dehra Dūn during 1928-29—(contd.).*

No.	Date	Indian standard time					Intensity of record	Distance	Remarks
		1st P. T.	2nd P. T.	Long wave	Maximum	Finish			
	1929	*h m s*	*h m s*	*h m s*	*h m*	*h m*		miles	
31	Mar. 10	20 15 00†	...	...	20 24	20 28	slight	...	
32	„ 13	16 33 30	16 34 00†	16 35 10	16 35	16 42	slight	400	
33	„ 19	...	...	...	5 25	...	slight	...	
34	„ 20	2 45 00†	...	...	4 24	4 49	slight	...	
35	„ 21	8 29 00†	8 40 00†	8 53 00†	9 25	10 34	slight	6200	
36	„ 22	8 38 10†	8 43 20	8 46 50	8 47	9 16	slight	2100	
37	„ 24	1 40 00†	1 47 00†	1 54 00†	1 55	2 13	slight	3300	
38	„ 25	9 20 50	9 23 20	9 25 00	9 26	9 50	sligh	900	
39	„ 29	2 07 00†	2 19 00†	2 36 00†	2 59	7 22	slight	6900	
40	Apr. 1	1 54 40	2 05 00†	2 19 00†	2 22	3 21	slight	6000	
41	„ 8	15 55 00†	15 57 00†	16 01 00†	16 05	16 33	slight	1200	
42	„ 11	5 20 00†	5 23 00†	5 24 00†	5 28	7 10	slight	900	
43	May 1	0 28 00†	0 32 00	0 35 00†	0 40	0 50	slight	1700	
44	„ 1	21 12 00	21 15 20	21 17 20	21 26	21 54	severe	1300	Trans-Caspian territory in Turkistan, N. E. coast of Persia.
45	„ 2	20 12 50	20 17 00†	20 25 00†	20 27	20 53	slight	2200	
46	„ 3	21 57 00†	...	...	21 59	22 10	slight	...	
47	„ 5	22 33 00†	22 41 00†	22 48 00†	22 52	23 13	slight	4000	
48	„ 6	10 57 30	11 01 00†	11 06 00†	11 07	11 42	slight	1600	
49	„ 7	22 24 00†	22 29 00†	22 32 00†	22 32	23 12	slight	1900	
50	„ 13	18 57 00†	19 03 00†	19 07 00†	19 08	19 33	slight	2300	
51	„ 18	12 18 00†	12 22 20	12 26 20	12 31	13 30	moderate	1700	
52	„ 20	10 35 00†	10 44 00†	10 58 00†	11 08	12 33	slight	5300	
53	„ 21	22 14 00†	22 20 20	22 29 30	22 35	23 50	moderate	3400	
54	„ 23	1 56 00†	02 05 00†	2 11 00†	2 33	3 08	slight	4100	
55	„ 25	0 14 50	0 17 20	0 19 20†	0 21	0 41	slight	1000	
56	„ 26	14 23 00†	14 31 00†	14 39 00†	14 49	15 14	slight	4100	
57	„ 27	4 24 00†	4 35 10	4 52 00†	5 08	7 37	severe	6600	Probably in Mendoza, Argentine.
58	June 3	3 17 00†	3 23 00†	3 29 00†	3 38	4 18	slight	2900	
59	„ 4	2 03 40	2 06 10	2 08 00	2 10	2 57	slight	1000	
60	„ 4	12 41 20	12 42 30	2 43 30	12 45	13 01	slight	500	
61	„ 4	20 54 20	21 01 00	21 07 00†	21 08	21 41	slight	3100	

† Recognized with difficulty.

(Continued).

TABLE 12.—*Earthquakes recorded at Dehra Dūn during 1928-29—(concld.).*

No.	Date	Indian standard time					Intensity of record	Distance	Remarks.
		1st P. T.	2nd P. T.	Long wave	Maxi-mum	Finish			
	1929	h m s	h m s	h m s	h m	h m		miles	
62	June 5	14 40 00†	14 43 00†	14 46 00†	14 47	14 58	slight	1300	
63	,, 9	14 47 40	14 55 40	15 07 00†	15 14	16 36	slight	4400	
64	,, 11	4 43 00†	4 50 00†	4 58 00†	5 08	5 33	slight	3600	
65	,, 12	17 20 00†	17 27 00†	17 33 00†	17 34	18 12	slight	3000	
66	,, 12	20 08 00†	20 10 00†	20 14 00†	20 16	20 32	slight	1000	
67	,, 13	2 47 00†	2 58 00†	3 16 00†	3 48	5 40	slight	7100	
68	,, 13	5 52 00†	6 01 00†	6 13 00	6 32	8 43	moderate	4700	
69	,, 13	15 03 30	15 10 40	15 16 00†	15 25	18 37	moderate	3200	
70	,, 17	4 36 30	4 46 00	4 52 50	5 18	6 57	great	4500	New Zealand North Island.
71	,, 17	15 55 00†	16 02 00†	16 13 00†	16 29	16 55	slight	3700	
72	,, 18	19 43 50	...	...	19 44	19 55	slight		
73	,, 19	13 10 00†	13 16 50	13 27 00†	13 35	14 25	slight	3700	
74	,, 27	18 36 40	18 48 00	19 06 40	19 21	22 26	moderate	7000	
74a	,, 30	...	...	...	†8 40	9 40	slight	...	Beginning missed while changing drum.
75	July 4	14 58 00†	15 02 00†	15 05 00†	15 28	16 01	slight	1600	
76	,, 4	17 39 00†	17 41 00†	17 43 00†	17 45	18 01	slight	1000	
77	,, 5	20 00 00†	20 10 00†	20 27 00†	20 35	22 23	moderate	6100	Probably Atlantic Ocean off the coast of Brazil.
78	,, 6	4 17 00†	4 27 00†	4 42 00†	4 52	5 56	slight	5700	
79	,, 8	3 04 50	3 14 30	3 23 00†	3 38	6 48	moderate	4900	
80	,, 13	13 10 00†	13 14 20	13 17 00†	13 20	13 52	slight	1400	
81	,, 14	14 58 00†	15 09 00†	15 29 00†	15 44	16 58	slight	7000	
82	,, 15	13 23 40	13 26 50	13 29 50	13 31	14 28	slight	1300	
83	,, 17	14 20 00†	14 30 00†	14 48 00†	14 58	15 29	slight	6300	
84	,, 24	0 33 00†	0 41 00†	0 51 00†	0 54	1 21	slight	3900	
85	,, 25	5 52 00†	...	5 57 20	5 59	6 30	slight	1200	
86	Aug. 1	10 36 50	10 41 20	10 44 50	10 47	11 17	slight	1800	
87	,, 1	20 02 40	..	20 05 00†	20 07	20 13	slight	500	
88	,, 8	18 31 40	18 35 20	18 39 20	18 43	19 28	moderate	1600	
89	,, 19	8 20 00†	8 26 20	8 34 10	8 38	9 36	slight	3100	
90	,, 20	...	...	...	2 37	2 54	slight	...	
91	,, 20	22 21 40	22 25 00†	22 29 50	22 32	22 55	slight	1500	
92	,, 29	...	...	...	0 59	1 35	slight	...	
93	Sept. 2	16 58 40	...	17 13 00†	17 20	17 52	slight	3500	
94	,, 3	17 41 10	17 43 40	17 46 00†	17 48	18 06	slight	1000	
95	,, 12	4 02 10	...	4 10 00†	4 13	4 33	slight	1900	
96	,, 24	19 24 30	19 25 10†	19 25 50	19 26	19 42	slight	200	

† Recognized with difficulty.

Chapter III

TIDES

BY LT.-COLONEL C.M. THOMPSON, I.A.

1. Tidal observations.—During the year under report, registration by automatic tide-gauges was continued at the following stations :— Aden, Karāchi, Bombay (Apollo Bandar), Madras, Kidderpore, Rangoon, Bassein and Basrah. These observations were carried out under the supervision of this department, the immediate control of each observatory being entrusted to the local officers of the port concerned. 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 officials at Bhāvnagar, Chittagong and Akyab, and throughout the day and night at Pilakāt or Deserters' Creek. The results of these actual observations were compared against the predicted values, with a view to testing whether the predictions, which were based on tidal observations taken many years ago, still maintained a sufficient degree of accuracy.

Table 1 gives a complete list of stations where tidal registrations have been carried out since the commencement of tidal operations in India in 1874. The stations at which automatic tide-gauges are still working are shown in italics. Minor stations were closed after a few years, when sufficient data were available from the tidal registrations.

TABLE 1.—*List of Tidal Stations.*

Station	Automatic or visual observations	Date of commencement of observations	Date of closing of observations	Number of years of observations	Remarks
Suez ...	automatic	1897	1903	7	
Perim ...	,,	1898	1902	5	
Aden ...	,,	1879	still working	50	
Maskat ...	,,	1893	1898	5	
Basrah ...	visual	1916	1922	7 } 14	
Basrah ...	automatic	1922	still working	7 }	

(*Continued*).

TABLE 1.—*List of Tidal Stations.*—(*contd.*).

Station	Automatic or visual observations	Date of commencement of observations	Date of closing of observations	Number of years of observations	Remarks
Bushire ...	automatic	1892	1901	8	
Karāchi ...	,,	{ 1868 1881	1880 still working	*13 } 61 48 }	*Small tide-gauge.
Navānar ...	,,	1874	1875	1	Tide-tables not published.
Hanstal ...	,,	1874	1875	1	,, ,, ,,
Okha Point ...	,,	{ 1874 1904	1875 1906	1 } 2 1 }	1904-05 excluded.
Porbandar ...	visual	1893	1894	2	
Porbandar ...	automatic	1898	1902	2	1898, 1899 & 1902 excluded.
Port Albert Victor (Kāthiāwār) ...	visual	1881	1882	1	
Port Albert Victor (Kāthiāwār) ...	automatic	1900	1903	4	
Bhāvnagar ...	,,	1889	1894	5	
Bombay (Apollo Bandar) ...	,,	1878	still working	51	
Bombay (Prince's Dock) ...	,,	1888	1925	37	
Mormugao (Goa) ...	,,	1884	1889	5	
Kārwār ...	,,	1878	1883	5	
Beypore ...	,,	1878	1884	6	
Cochin ...	,,	1886	1892	6	
Minicoy ...	,,	1891	1896	5	
Tuticorin ...	,,	1888	1893	5	
Pāmban Pass ...	,,	1878	1882	4	
Colombo ...	,,	1884	1890	6	
Galle ...	,,	1884	1890	6	
Trincomalee ...	,,	1890	1896	6	
Negapatam ...	,,	1881	1888	5	1883 to 1885 excluded.
Madras ...	,,	{ 1880 1895	1890 still working	10 } 44 34 }	
Cocanāda ...	,,	1886	1891	5	
Vizagapatam ...	,,	1879	1885	6	
False Point ...	,,	1881	1885	4	
Dublat (Sāgar Island)	,,	1881	1886	5	
Diamond Harbour ...	,,	1881	1886	5	
Kidderpore ...	,,	1881	still working	48	

(*Continued*).

TABLE 1.—*List of Tidal Stations*—(*concld.*).

Station	Automatic or visual observations	Date of commencement of observations	Date of closing of observations	Number of years of observations	Remarks
Chittagong ...	automatic	1886	1891	5	
Akyab ...	"	1887	1892	5	
Diamond Island ...	"	1895	1899	5	
Bassein (Burma) ...	"	{ 1902 1923	1903 1929	2 } 7 5 }	
Elephant Point ...	"	{ 1880 } 1884 } 1927	1881 } 1888 } 1928 }	} 5 } 6 †1 }	1880-81 excluded.
Rangoon ...	"	1880	still working	49	
Moulmein ...	"	{ 1880 1909	1886 1924	6 } 22 16 }	
Amherst ...	"	1880	1886	6	
Mergui ...	"	1889	1894	5	
Port Blair ...	"	1880	1925	45	

2. **Inspections.**—*Burma.*—The tidal observatories at Bassein and Rangoon were inspected by Mr. D.H. Luxa, the tidal assistant, in February and March 1929. The tidal observations which were resumed at Bassein at the request of the Port Advisory Board in November 1923, after a lapse of nearly 20 years, were brought to a close on the 28th February 1929, when the automatic tide-gauge and its component parts were dismantled.

India.—The inspection of the tidal observatories at Madras and Kidderpore (Calcutta) was also carried out by Mr. Luxa, the former in February and the latter in March 1929. The inspection of the tidal observatory at Madras was carried out at the request of the Chief Engineer, Madras Port Trust. The old tidal observatory at Madras, which was built early in 1914, having become very unstable, a new one was built alongside it, and an inspection of both the old and new observatories was carried out. The registration of the tidal curves at the old observatory was stopped at 3-0 p.m. on the 12th February 1929, and was resumed in the new observatory at 4 p.m. on the 15th February 1929.

The inspection of the tidal observatory at Apollo Bandar, Bombay, was carried out by the Surveyor, Port Trust, Bombay, in March 1929. The Karāchi tidal observatory was last inspected in January 1928, by the Harbour Surveyor of the Port Trust, and no further reports regarding inspections have been received from him since then. In the case of Aden also, no reports have been received as to whether the tidal observatory has been inspected or not.

† Observations were resumed at the Pilakāt or Deserters' Creek, about ¼ mile west of the site used in 1884-88.

It was last inspected by an officer of the Survey of India in October 1924. Except for minor stoppages, all the tide-gauges have worked satisfactorily.

3. Harmonic analysis.—The reduction of the tidal observations at Bassein for the year 1927, have been fully reduced by the method of harmonic analysis. The resulting values of the harmonic constants are given in Table 2.

TABLE 2.—*Values of the tidal constants for Bassein 1927.*

Tide symbol	1927				Tide symbol	1927			
	$A_0 = 8 \cdot 309$					$A_0 = 8 \cdot 309$			
	R	ζ	H	κ		R	ζ	H	κ
Short period	*feet*		*feet*		Short period	*feet*		*feet*	
S_1	0·064	139°·95	0·064	139°·95	N_2	0·400	248°·54	0·400	41°·36
S_2	0·717	93·22	0·717	93·22	ν_2	0·220	20·38	0·221	27·03
S_4	0·014	58·63	0·014	58·63	μ_2	0·259	78·44	0·260	183·32
S_6	0·003	68·96	0·003	68·96	T_2	0·160	34·67	0·160	36·48
S_8	0·003	39·29	0·003	39·29	$(MS)_4$	0·171	321·16	0·171	13·60
M_1	0·019	139·01	0·000	76·22	$(2SM)_2$	0·087	354·17	0·087	301·73
M_2	2·222	359·71	2·225	52·16	$2N_2$	0·072	232·68	0·072	125·87
M_3	0·013	300·65	0·013	19·31	$(M_2N)_4$	0·049	185·58	0·049	30·83
M_4	0·244	232·87	0·245	337·75	$(M_2K_1)_3$	0·066	88·38	0·064	321·98
M_6	0·085	96·00	0·085	253·33	$(2M_2K_1)_3$	0·075	347·89	0·074	271·62
M_8	0·026	340·22	0·026	180·99					
O_1	0·172	162·96	0·167	38·11					
K_1	0·375	226·04	0·368	47·20	Long period				
K_2	0·188	263·42	0·183	85·49	Mm	0·080	183·05	0·090	82·67
P_1	0·123	250·10	0·123	60·22	Mf	0·068	203·61	0·064	55·69
					MSf	0·297	95·30	0·297	42·86
J_1	0·023	317·69	0·022	34·58					
Q_1	0·022	58·53	0·021	34·09	Sa	1·970	237·55	1·970	157·43
L_2	0·165	295·89	0·247	66·45	Ssa	0·342	162·51	0·342	2·27

4. Corrections to predictions.—Comparison of the predicted times and heights of high- and low-waters with those actually recorded, has indicated that the corrections shown below should be applied to the predictions for Rangoon and Chittagong. They have been included in the tide-tables for 1930. These corrections are instead of (not additional to) those already included in the tide-tables between 1927 and 1929 (See Geodetic Reports, Vols. II, III and IV).

TABLE 3.—*Time corrections applied to Rangoon for 1930.*

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

The above corrections are based on the mean fortnightly results of the comparisons between predicted and actual differences from 1923 to 1928, computed for 5-day periods.

TABLE 4.—*Corrections to Chittagong predictions for 1930.*

Tide	Correction to Time	Correction to Height
	minutes	*feet*
High-water	+ 14	+ 0·2
Low-water	+ 14	+ 0·7

The above corrections are based on the mean results of the fortnightly differences between predicted and actual values between 1923 and 1928.

Basrah.—The revised method of corrections applied to the predictions of Basrah for 1929, was again adopted in the predictions for 1930. Comparisons made between predicted and actual times and heights of high- and low-waters at Basrah from January to July 1929 show that the predictions have undergone little or no improvement. With the view to trying to improve matters, other methods of prediction for Basrah are being tested, and the question is still under investigation.

5. **Tide-tables.**—The tide-tables for Basrah and the Indian ports for 1930 were prepared and published, and their distribution completed by the end of October 1929. Advance copies of the 1930 tide-tables for the following ports:—Suez, Aden, Bushire, Karāchi, Bhāvnagar, Bombay, Mormugao, Colombo, Trincomalee, Madras, Dublat (Sāgar Island), Chittagong, Elephant Point and Mergui, were prepared and despatched to the Hydrographer to the Admiralty by the end of February 1929, for incorporation in the Admiralty tide-tables for 1930. The amount realized by the sale of tide-tables during the year ending 30th September 1929, amounted to Rs. 6,160/8/-, exclusive of agents' commission charges and the cost of copies issued gratis.

6. **Proposed tide-tables for the Indian Ocean.**—As a result of the discussion between the Surveyor General of India and the Hydrographer to the Admiralty in 1928, proposals have been submitted to the Government of India, to discontinue, in so far as possible, the present pamphlet form in which the tide-tables for India have been published, and to publish them in one combined volume instead, styled "Tide-tables of the Indian Ocean". The new volume will not only contain full tide-tables for the 40 Indian ports, hitherto predicted by the Survey of India, but also, with the consent of the Admiralty and other authorities concerned, full tide-tables for 28 other standard ports. In addition, harmonic and non-harmonic constants and tidal differences for a number of the more important ports situated on the south and east coasts of Africa, the Indian Ocean, the China Sea and Eastern Archipelago, as well as for a few Mediterranean and Home ports will be given. The new volume will be

similar in style to the Admiralty Tide-tables, Part I (annual) and Part II (quinquennial), but will be published as a single annual volume. In this form it is hoped these tables will be more convenient for shipping companies which carry the Eastern trade. The price proposed for the new publication is Rs. 3/- only, while that of the present major series volume is Rs. 8/- and the prices of the pamphlets range from -/12/- annas to Rs. 1/8/-. The publication of these small pamphlets is uneconomic, except in the case of the large ports such as Bombay, Calcutta and Rangoon, of which over 800 pamphlets of each can be sold. It is hoped that the sale will increase in view of the additional information supplied in the tables, and the decreased cost.

7. Accuracy of predictions.—From comparisons made between predicted and actual times and heights of high- and low-waters, at the eight stations where automatic tide-gauges were in operation and the 4 stations at which tide-poles were in use, the predictions for 1928 were found to have shown a marked improvement as regards height, especially of high-water, and to a lesser extent as regards time of low-water. A deterioration in time of both high- and low-waters was noticed at Bhāvnagar, Chittagong and Pilakāt or Deserters' Creek, though a marked improvement as regards heights of both high- and low-waters was seen at these three stations and also at Basrah and Akyab. The greatest improvement was noticed at Kidderpore, and to a lesser extent at Aden, Karāchi and Madras. The greatest differences between the predicted and actual heights of low-water at the riverain ports were as follows:—

Port	Predicted *minus* actual in feet	Date
Kidderpore ...	+ 2·9	24th September 1928
Rangoon ...	− 2·5	30th October 1928
Pilakāt or Deserters' Creek ...	− 1·8	29th October 1928
Bassein ...	− 3·2	30th & 31st October and 1st November 1928
Basrah ...	+ 4·6	3rd March 1928

Tables 5 to 16 give the fortnightly mean errors in the predictions for all stations at which comparisons were made.

TABLE 5.—*Mean errors E_1 and E_2 for 1928.*

ADEN

PERIOD 1928	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.	0·7 feet of height H. W.	L. W.
Jan. 1-15		1·4		0·1	3·5			0·1	9·8	0·1	11·8	0·1	1	2	0	0
16-31	3·3		0·0		1·6			0·0	8·0	0·1	7·8	0·1	1	0	0	0
Feb. 1-15	1·3		0·1		10·3		0·0		7·8	0·2	13·5	0·1	1	2	0	0
16-29		13·8	0·2		3·5		0·2		19·2	0·2	15·3	0·2	5	2	0	0
Mar. 1-15		1·0	0·0		5·4		0·0		13·2	0·1	9·9	0·1	2	1	0	0
16-31	11·9		0·1		12·3		0·1		18·7	0·2	29·0	0·1	5	6	0	0
April 1-15	11·9			0·0	5·4		0·0		17·0	0·2	13·6	0·1	4	1	0	0
16-30	12·2		0·1		10·9		0·1		14·8	0·2	14·8	0·2	3	2	0	0
May 1-15	11·2		0·1		0·1		0·0		13·9	0·1	12·5	0·1	2	2	0	0
16-31	4·8			0·0	4·2			0·1	7·7	0·1	9·3	0·1	0	2	0	0
June 1-15	2·4			0·0	4·5			0·0	5·3	0·1	6·7	0·1	0	0	0	0
16-30	6·5			0·1	7·1			0·1	10·2	0·2	9·9	0·1	2	0	0	0
July 1-15	6·7			0·0	9·3		0·1		10·2	0·1	11·4	0·1	0	0	0	0
16-31	0·2			0·2	7·3			0·2	13·1	0·2	13·8	0·2	3	3	0	0
Aug. 1-15	6·0			0·1	6·7		0·0		9·8	0·1	7·8	0·1	1	0	0	0
16-31	4·0		0·0		8·4		0·0		10·7	0·1	13·4	0·1	1	2	0	0
Sept. 1-15	1·1			0·0	4·4		0·0		8·3	0·1	8·4	0·1	1	0	0	0
16-30	3·1			0·1	7·7			0·1	8·5	0·1	10·4	0·2	0	1	0	0
Oct. 1-15	4·8			0·0	4·4			0·1	8·6	0·1	10·2	0·1	0	2	0	0
16-31	4·7		0·1		10·0			0·1	10·6	0·1	11·0	0·1	1	1	0	0
Nov. 1-15	3·7		0·0		2·9			0·0	8·9	0·1	8·6	0·1	1	1	0	0
16-30		3·7	0·1			0·4	0·1		8·9	0·1	10·5	0·2	0	2	0	0
Dec. 1-15		1·9		0·0	2·9			0·1	9·1	0·2	9·4	0·1	1	0	0	0
16-31		1·4	0·1		0·9		0·1		8·7	0·2	8·2	0·2	0	1	0	0
TOTALS ...	99·8	23·2	0·9	0·6	133·7	0·4	0·7	0·9	261·0	3·3	277·2	3·0	35	33	0	0
MEANS ...	+ 3·2		+ 0·0		+ 5·6		− 0·0		10·9	0·1	11·6	0·1	...	...	...	...

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

TABLE 6.—*Mean errors E and E_2 for 1928.*

BASRAH

PERIOD 1928	MEAN ERRORS (Predicted—actual) E₁* H. W. Time minutes +	−	H. W. Height feet +	−	L. W. Time minutes +	−	L. W. Height feet +	−	E₂* 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.	30 minutes of time L. W.	0·6 feet of height H. W.	0·6 feet of height L. W.
Jan. 1-15	3·0		1·4		28·1		1·5		38·0	1·4	52·3	1·6	16	19	27	25
16-23	35·2		0·2		38·0		0·3		47·2	0·5	53·7	0·5	8	9	5	9
Feb. 1-15	3·9		0·1		20·7		0·6		30·9	0·6	45·7	0·8	9	15	8	19
16-29	20·7		0·3		34·3		0·6		38·1	0·5	54·6	0·8	13	15	9	15
Mar. 1-15	4·5		1·1		27·9		1·9		32·3	1·1	46·9	1·9	12	14	17	27
16-31		21·7	0·6		5·1		1·5		50·6	0·7	43·2	1·5	18	18	17	28
April 1-15		8·3	1·1		12·2		2·1		52·0	1·1	22·5	2·1	16	9	19	24
16-30	7·3		1·6		23·6		2·6		49·2	1·6	44·8	2·6	17	17	25	25
May 1-15	17·3		2·0		22·0		2·9		47·6	2·0	34·5	2·9	15	12	27	25
19·31		18·3	1·2			21·3	1·6		27·0	1·2	44·9	1·6	7	15	23	23
June 1-15	1·7		1·5		10·5		2·2		45·0	1·5	47·2	2·2	19	21	28	29
16-30	22·7		1·1		35·1		1·9		39·3	1·1	54·9	1·9	16	15	28	27
July 1-15		2·8	1·0		26·0		1·9		36·9	1·0	53·1	1·9	18	18	26	29
16-31		12·4	0·6		12·8		1·4		45·2	0·6	56·8	1·4	21	23	18	31
Aug. 1-15	5·2		0·5		15·7		1·0		34·2	0·5	58·3	1·0	14	20	10	26
16-31	22·4		0·1		31·9		0·6		50·7	0·3	61·8	0·8	20	22	5	20
Sept. 1-15	11·2		0·0		26·0		0·4		39·3	0·4	51·3	0·6	17	22	6	11
16-30	21·8			0·0	22·4		0·3		42·0	0·4	43·3	0·5	12	16	9	11
Oct. 1-15		3·6	0·3		12·1		0·4		45·2	0·3	44·4	0·5	18	16	9	12
16-31	27·7		0·3		45·0		0·4		54·9	0·5	47·5	0·8	17	15	8	19
Nov. 1-15	7·5			0·1	20·4		0·3		47·1	0·4	42·1	0·7	16	15	8	14
16-30		2·7		0·1	13·1			0·2	48·4	0·5	46·8	0·7	21	23	10	14
Dec. 1-15	30·4			0·6	44·4		0·0		46·9	0·6	57·0	0·6	16	19	16	16
16-31	15·6			0·0	29·3		0·3		47·0	0·5	53·0	0·7	20	19	15	16
TOTALS...	258·1	69·8	15·0	0·8	556·6	21·3	26·7	0·2	1035·0	19·3	1160·6	30·6	376	407	373	495
MEANS ...	+ 7·8		+ 0·6		+ 22·3		+ 1·1		43·1	0·8	48·4	1·3	...	...	...	...

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

TABLE 7.—*Mean errors E_1 and E_2 for 1928.*

KARĀCHI

PERIOD 1928	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.	0·9 feet of height H. W.	L. W.
Jan. 1-15		2·7		0·2		2·8	0·1		8·4	0·3	9·8	0·2	0	0	0	0
16-31		0·3		0·3	1·3			0·1	10·8	0·3	7·3	0·2	0	1	0	0
Feb. 1-15	0·6			0·2	5·6			0·0	7·3	0·2	11·1	0·2	0	2	0	0
16-29		2·1		0·2	4·6			0·1	9·4	0·3	11·7	0·2	0	2	0	0
Mar. 1-15	0·2			0·3	2·9			0·1	9·3	0·3	11·1	0·2	1	3	0	0
16-31		1·7		0·4	5·6			0·2	8·3	0·4	9·8	0·2	1	1	0	0
April 1-15		9·0		0·3		1·3		0·1	11·0	0·3	7·7	0·2	1	0	0	0
16-30		6·8		0·0	0·7		0·2		8·4	0·2	8·5	0·3	0	1	0	0
May 1-15		11·2		0·3		5·3		0·2	12·0	0·3	8·9	0·2	0	0	0	0
16-31		8·2		0·3		2·6		0·2	9·6	0·3	8·1	0·2	0	0	0	0
June 1-15		6·7		0·1	0·9			0·0	9·2	0·2	8·8	0·2	0	0	0	0
16-30		5·2	0·1			7·6	0·1		7·9	0·3	11·6	0·3	0	1	0	0
July 1-15		8·7	0·1			2·7	0·2		12·2	0·2	10·0	0·3	3	0	0	0
16-31		6·9		0·3		7·8		0·2	10·5	0·3	10·8	0·2	1	3	0	0
Aug. 1-15		4·3		0·4		1·5		0·2	7·5	0·4	6·8	0·2	0	0	0	0
16-31		5·6		0·1		5·1		0·0	10·2	0·2	8·7	0·2	1	2	0	0
Sept. 1-15		3·0		0·3		0·2		0·0	9·1	0·3	7·2	0·1	0	1	0	0
16-30		4·0		0·1		0·4		0·0	9·8	0·2	5·4	0·2	0	0	0	0
Oct. 1-15		1·1	0·1		0·6		0·3		11·2	0·2	8·1	0·3	2	0	0	0
16-31		7·7	0·1		1·8		0·1		14·2	0·2	9·2	0·2	3	0	0	0
Nov. 1-15		9·2		0·1	2·8		0·0		12·1	0·2	8·7	0·2	2	0	0	0
16-30		8·6		0·4		2·5		0·2	11·6	0·4	11·5	0·3	0	1	0	0
Dec. 1-15		13·7		0·0		11·2	0·1		14·6	0·2	13·3	0·1	4	1	0	0
16-31		5·5		0·1	1·4		0·1		6·8	0·2	9·7	0·3	0	0	0	0
TOTALS	0·8	132·2	0·4	4·4	28·2	51·0	1·2	1·6	241·4	6·4	223·8	5·2	19	19	0	0
MEANS	− 5·5		− 0·2		− 1·0		− 0·0		10·1	0·3	9·3	0·2	...	...	...	...

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

TABLE 8.—*Mean errors E_1 and E_2 for 1928.*

BHĀVNAGAR

PERIOD 1928	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.	1·0 feet of height H. W.	L. W.
Jan. 1-15	3·5			0·5		18·1		0·2	16·9	0·5	18·3	0·8	0	2	2	4
16-31	6·3			0·0		11·4		0·2	12·4	0·5	12·1	0·5	1	1	1	1
Feb. 1-15	8·7			0·2		16·7		0·2	13·7	0·6	22·1	0·8	1	2	1	4
16-29	5·7			0·1		14·5		0·5	7·9	0·6	18·9	1·2	0	3	2	7
Mar. 1-15	12·1			0·6		18·8		0·4	16·8	0·7	22·1	1·0	4	4	6	6
16-31	7·3			0·4		30·6		0·8	11·3	0·6	32·4	1·1	0	7	5	5
April 1-15	10·7			0·3		17·9		0·2	12·8	0·4	24·2	0·6	0	3	0	3
16-30	4·8			0·2		42·6		0·2	12·9	0·9	43·0	1·0	1	8	5	6
May 1-15	14·3			0·4		5·1		0·1	14·3	0·5	12·0	0·6	0	0	0	2
16-31	6·2			0·2		34·8		0·5	12·7	0·8	26·0	0·5	1	6	6	3
June 1-15	10·1		0·1			10·8	1·0		11·1	0·4	11·3	1·0	0	1	0	5
16-30	6·3			0·1		24·3	0·3		10·9	0·8	24·3	0·5	1	6	4	1
July 1-15	11·3		0·0			16·2	1·4		11·4	0·4	16·5	1·4	0	2	0	10
16-31	11·2			0·7		13·9	0·4		16·8	0·8	18·1	0·6	0	5	5	2
Aug. 1-15	7·4			0·8		21·5	1·0		10·2	0·8	24·7	1·0	0	5	4	6
16-31	13·3			0·1		8·9	0·9		15·6	0·5	15·5	0·9	1	2	2	4
Sept. 1-15	11·9			0·6		20·9	0·5		12·7	0·6	25·1	0·6	0	7	2	3
16-30	16·0			0·0		11·3	0·6		18·1	0·2	21·4	0·7	1	4	0	5
Oct. 1-15	9·0			0·2		17·9	0·6		13·5	0·6	23·2	0·8	0	5	1	6
16-31	6·5		0·3			16·5	0·5		14·5	0·5	19·6	0·8	1	4	2	4
Nov. 1-15	1·2			0·2		22·1	0·3		12·9	0·6	22·1	0·7	0	4	1	3
16-30	9·5			0·2		12·3		0·4	18·5	0·5	16·3	0·8	2	3	1	4
Dec. 1-15		2·3		0·2		19·6	0·1		14·5	0·5	19·6	0·5	0	3	2	0
16-31	5·6		0·2			16·3		0·3	19·3	0·6	16·3	1·1	5	2	2	6
TOTALS...	198·9	2·3	0·6	6·0		443·0	7·6	4·0	330·7	13·9	515·1	19·5	19	89	54	100
MEANS ...	+ 8·2		− 0·2		− 18·5		+ 0·2		13·8	0·6	21·5	0·8	...	...	...	...

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

TABLE 9.—*Mean errors E_1 and E_2 for 1928.*

BOMBAY (APOLLO BANDAR)

PERIOD 1928	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		6·1	0·1			7·5	0·3		7·2	0·2	9·0	0·4	0	0	0	0
16-31		4·3	0·0			8·5	0·1		6 1	0·2	9 6	0·3	0	1	0	0
Feb. 1-15		5·9	0·2			2·2	0·3		7·9	0·3	5·8	0·4	0	0	0	0
16-29		3·0	0·0			3·1	0·1		6·1	0·3	6 3	0·2	0	0	0	0
Mar. 1-15		5·0		0·0		3·6	0·1		7 2	0·2	9·4	0·3	0	1	0	0
16-31		4·7		0·2		3·0		0·2	7·8	0·2	7·8	0·4	0	0	0	0
April 1-15		1·2		0·4		0 0		0·2	7·7	0 5	7 1	0·2	0	0	0	0
16-30		1·8	0·1			2·5	0·2		9·5	0·2	6 5	0·4	0	0	0	1
May 1-15		3 6		0·5	0·1			0 3	5·0	0 5	4 9	0·3	0	0	0	0
16-31	0·5			0 1		6·8		0·0	6 7	0·2	9 5	0·3	0	1	0	0
June 1-15		0·3	0·1			2·2	0·3		4·8	0·2	4 7	0·3	0	0	0	0
16-30		3·2		0·0		6·2	0·1		5·0	0·2	8·8	0·3	0	0	0	0
July 1-15	1·6		0·1		9·4		0 2		7·2	0·2	12 0	0·3	0	2	0	0
16-31		1 5		0·5	1·0			0·5	7 8	0·5	7 5	0·5	0	1	3	1
Aug. 1-15	0·4			0·2		1·8		0·2	5 1	0·3	9·2	0·3	0	1	0	0
16-31		4 1	0·1			4·2		0·1	10 8	0·2	6·4	0·3	3	1	0	0
Sept. 1-15	0·7		0·1		7·1			0·0	7·2	0·2	8·4	0·2	1	0	0	0
16-30		10·2	0·1			10·4	0·1		13·3	0·2	11·4	0·2	3	2	0	0
Oct. 1-15		2·5	0·3		1·2		0·1		7·3	0·3	8·1	0·3	1	1	0	0
16-31		9·6	0·2			6·2	0·2		10·2	0·3	7·6	0 3	1	2	0	0
Nov. 1-15		2·5	0·2			1·2		0·0	4·3	0·3	4·5	0·2	0	0	0	0
16-30		4 0		0·2		8·8		0·2	8·3	0·3	5·7	0·3	2	1	0	0
Dec. 1-15		6·6	0·0			11·7		0·1	8·5	0·3	12·7	0·2	1	2	0	0
16-31		5·9		0·1		9·4		0·0	7·9	0·2	10 6	0·3	0	0	0	0
TOTALS ..	3·2	86·0	1·6	2·2	18·8	94·3	2·1	1·8	178·9	6·5	193·5	7·2	12	16	3	2
MEANS ..	− 3·5		− 0·0		− 3·1		+ 0·0		7·5	0·3	8·1	0·3	...	...	...	...

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

TABLE 10.—*Mean errors* E_1 *and* E_2 *for 1928.*

MADRAS

PERIOD 1928	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	2·0		0·0		0·6			0·0	3·9	0·1	4·8	0·1	0	0	0	0
16-31	2·4			0·0	1·7		0·0		4·9	0·1	5·2	0·2	0	0	0	0
Feb. 1-15		1·4		0·1	1·5			0·0	5·3	0·1	3·7	0·1	0	0	0	0
16-29	2·4		0·0		3·3			0·0	4·2	0·1	4·1	0·1	0	0	0	0
Mar. 1-15	4·1			0·5	3·1			0·4	5·0	0·5	6·1	0·4	0	0	19	12
16-31	2·9			0·3	3·1			0·3	6·3	0·3	7·1	0·3	0	0	4	6
April 1-15	3·4			0·1	3·2			0·1	6·0	0·2	6·4	0·2	0	0	0	0
16-30	3·9			0·1	7·1			0·1	4·2	0·1	7·9	0·1	0	0	0	0
May 1-15	1·6			0·1	1·8		0·1		3·9	0·1	4·2	0·1	0	0	0	0
16-31	1·2		0·2		2·0		0·2		3·0	0·2	4·1	0·2	0	0	1	1
June 1-15		2·8	0·0			1·4	0·0		5·0	0·1	3·7	0·1	0	0	0	0
16-30		1·1	0·1		0·8		0·1		4·7	0·2	3·2	0·1	0	0	0	0
July 1-15		1·2		0·2		1·4		0·1	4·5	0·2	5·7	0·2	0	0	4	1
16-31		1·1		0·0	0·2			0·0	4·1	0·2	3·3	0·2	0	0	3	1
Aug. 1-15		0·1		0·3	0·6			0·2	2·6	0·3	1·9	0·2	0	0	2	0
16-31		5·8		0·1		5·2		0·1	6·2	0·2	6·3	0·2	0	0	0	0
Sept. 1-15		2·1	0·0			1·4	0·1		5·4	0·1	6·3	0·1	0	0	0	0
16-30	3·9		0·2		2·6		0·2		5·2	0·2	3·5	0·3	0	0	0	4
Oct 1-15		1·6	0·2		0·1		0·2		3·8	0·2	5·6	0·2	0	0	1	3
16-31		1·6	0·1			0·2	0·2		5·4	0·1	4·3	0·2	0	0	0	2
Nov. 1-15	1·5			0·3	4·4			0·2	4·7	0·3	7·0	0·2	0	0	5	2
16-30	4·2		0·0		3·5		0·1		5·4	0·1	5·1	0·1	0	0	0	0
Dec. 1-15	1·6			0·1	4·7		0·1		7·2	0·1	6·7	0·1	0	0	0	0
16-31		6·3		0·1		6·3		0·2	6·9	0·1	7·5	0·3	0	0	0	5
Totals...	35·1	25·1	0·8	2·3	44·3	15·9	1·3	1·7	117·8	4·2	123·7	4·3	0	0	39	37
Means...	+ 0·4		− 0·1		+ 1·2		− 0·0		4·9	0·2	5·2	0·2	...	...	..	...

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

TABLE 11.—*Mean errors E_1 and E_2 for 1928.*

KIDDERPORE

PERIOD 1928	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																
16-31																
Feb. 1-15																
16-29																
Mar. 1-15																
16-31																
April 1-15	The old tidal observatory was considerably damaged on the 5th November 1927 by the B.I.S.N. Co's. Steamer "Mundra" while entering the Kidderpore docks. No further tidal registrations were recorded until the 28th August 1928, when the observatory was reconstructed and registrations were restarted.															
16-30																
May 1-15																
16-31																
June 1-15																
16-30																
July 1-15																
16-31																
Aug. 1-15																
16-31																
Sept. 1-15		5·3	1·6			4·2	1·8		10·4	1·6	8·0	1·8	0	0	29	29
16-30		9·5	1·9			0·4	2·1		13·1	1·9	7·3	2·1	3	1	28	29
Oct. 1-15		11·3	0·8			9·0	1·2		12·7	0·9	10·3	1·2	3	0	12	18
16-31		0·7		0·4		4·3	0·5		11·6	0·4	15·1	0·5	1	1	3	5
Nov. 1-15		13·9	0·3			10·0	0·7		15·4	0·4	10·8	0·7	3	2	0	2
16-30		5·4		0·0		9·8	0·5		8·7	0·4	18·2	0·5	0	4	2	0
Dec. 1-15		7·5	0·1			1·9	0·3		12·1	0·2	7·4	0·4	0	0	0	0
16-31	4·4		0·0			3·1	0·1		11·5	0·2	8·5	0·4	1	0	0	0
TOTALS ..	4·4	53·6	4·7	0·4		42·7	7·2		95·5	6·0	85·6	7·6	11	8	74	83
MEANS ...	− 6·2		+ 0·5		− 5·3		+ 0·9		11·9	0·8	10·7	1·0	...	...	...	...

* E is with regard to sign : E is without regard to sign.

TABLE 12.—*Mean errors E_1 and E_2 for 1928.*

CHITTAGONG

PERIOD 1928	MEAN ERRORS (Predicted—actual) E_1* H. W. Time (minutes) +	E_1 H. W. Time (minutes) −	E_1 H. W. Height (feet) +	E_1 H. W. Height (feet) −	E_1 L. W. Time (minutes) +	E_1 L. W. Time (minutes) −	E_1 L. W. Height (feet) +	E_1 L. W. Height (feet) −	E_2* H. W. Time (minutes)	E_2 H. W. Ht. (feet)	E_2 L. W. Time (minutes)	E_2 L. W. Ht. (feet)	Number of errors exceeding 30 minutes of time H. W.	30 minutes of time L. W.	1·0 feet of height H. W.	1·0 feet of height L. W.
Jan. 1-15		12·9	0·2			12·7	0·1		15·6	0·2	14·1	0·3	0	0	0	0
16-31		9·5	0·1		2·6		0·2		11·4	0·4	7·8	0·3	2	0	0	0
Feb. 1-15		7·4	0·5			1·2		0·4	13·0	0·5	14·7	0·8	0	1	0	4
16-29		4·4		0·1		0·1		0·3	12·4	0·4	9·0	0·3	0	0	0	0
Mar. 1-15	0·7			0·4	4·4			0·2	9·6	0·6	13·5	0·6	0	0	3	2
16-31		11·5	0·6			7·2	0·2		15·9	0·8	11·6	0·3	1	0	6	0
April 1-15	2·1		0·3		2·3		0·5		6·5	0·5	12·5	0·5	0	1	0	2
16-30		9·5	0·2			7·9	0·2		12·0	0·6	10·6	0·4	1	0	4	0
May 1-15		9·9	0·3			1·4	0·3		9·9	0·4	8·1	0·4	0	0	0	0
16-31		11·4	0·6			8·4	0·3		11·5	0·6	9·1	0·6	0	0	4	1
June 1-15		12·7		0·3		8·8		0·1	12·7	0·6	11·3	0·5	2	0	2	1
16-30		8·0		0·0		8·7		0·2	9·1	0·2	10·7	0·5	0	0	0	1
July 1-15		12·1	0·1			1·3	0·2		12·8	0·3	7·0	0·2	0	0	0	0
16-31		2·7		0·3	4·4			0·4	5·1	0·4	6·7	0·5	0	0	0	0
Aug. 1-15		2·1	0·1			0·4	0·4		5·2	0·4	7·9	0·4	0	0	0	1
16-31	1·2			0·2	5·4			0·3	3·9	0·5	8·2	0·4	0	0	0	2
Sept. 1-15		4·7	0·3			1·6	0·5		6·1	0·3	8·6	0·5	0	0	1	0
16-30		7·8	0·0			2·3		0·3	8·2	0·2	6·8	0·4	0	0	0	2
Oct. 1-15		13·4		0·2		8·5		0·8	14·1	0·5	8·8	0·8	1	0	1	5
16-31		13·8		0·3		8·0		0·4	13·8	0·4	9·3	0·5	1	0	0	2
Nov. 1-15		18·3	0·1			9·9	0·0		18·3	0·3	10·5	0·2	1	0	1	0
16-30		12·9	0·2			10·8	0·2		13·5	0·5	10·8	0·4	0	0	0	0
Dec. 1-15		2·3	0·0			0·5	0·4		5·3	0·2	5·6	0·4	0	0	0	0
16-31	11·6			0·4	8·7			0·2	14·7	0·4	10·2	0·3	0	0	0	0
TOTALS ..	15·6	187·3	3·6	2·2	27·8	99·7	3·5	3·6	260·6	10·2	232·8	10·5	9	2	22	23
MEANS ...	− 7·2		+ 0·1		− 3·0		− 0·0		10·9	0·4	9·7	0·4	...	...	...	...

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

TABLE 13.—*Mean errors* E_1 *and* E_2 *for 1928.*

AKYAB

PERIOD 1928	MEAN ERRORS (Predicted—actual)												Number of errors exceeding			
	E1*								E2*				30 minutes of time		0·8 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	5·9		0·0		5·7		0·2		5·9	0·2	5·7	0·2	0	0	0	0
16-31	3·9			0·2	5·8			0·0	8·3	0·2	5·8	0·2	1	0	0	0
Feb. 1-15	6·1			0·0	5·6			0·0	6·1	0·1	5·6	0·1	0	0	0	0
16-29	7·0			0·2	5·1			0·0	7·0	0·2	5·1	0·1	0	0	0	0
Mar. 1-15	6·3			0·1	6·7		0·2		6·3	0·2	6·7	0·2	0	0	0	0
16-31	5·6			0·0	3·0		0·2		5·6	0·2	6·9	0·3	0	1	0	1
April 1-15	6·1			0·2	5·3			0·0	6·1	0·2	5·3	0·1	0	0	0	0
16-30	5·2			0·1	5·6		0·0		5·2	0·2	5·6	0·2	0	0	0	0
May 1-15	5·5			0·2	6·3		0·0		5·5	0·2	6·3	0·1	0	0	0	0
16-31	5·7			0·1	5·7		0·0		5·7	0·1	5·7	0·1	0	0	0	0
June 1-15	6·1			0·2	5·8			0·1	6·1	0·2	5·8	0·1	0	0	0	0
16-30	5·9			0·1	5·4		0·1		5·9	0·2	5·4	0·1	0	0	0	0
July 1-15	5·9			0·1	6·1		0·1		5·9	0·2	6·1	0·2	0	0	0	1
16-31	6·6			0·2	6·1			0·0	6·6	0·2	6·1	0·1	0	0	0	0
Aug. 1-15	4·9			0·2	5·5			0·1	4·9	0·3	5·5	0·1	0	0	0	0
16-31	5·5			0·1	5·8		0·4		5·5	0·3	5·8	0·5	0	0	1	3
Sept. 1-15	5·6			0·1	5·2		0·1		5·6	0·4	5·2	0·3	0	0	2	1
16-30	5·7			0·0	5·8		0·2		5·7	0·3	5·8	0·2	0	0	0	0
Oct. 1-15	5·5			0·5	5·0			0·3	5·5	0·5	5·0	0·3	0	0	4	1
16-31	6·1			0·2	5·1			0·4	6·1	0·3	5·1	0·5	0	0	0	3
Nov. 1-15	5·1			0·2	5·2		0·1		5·1	0·4	5·2	0·3	0	0	4	0
16-30	4·9		0·1		5·0		0·1		5·6	0·4	5·0	0·4	0	0	2	2
Dec. 1-15	6·1		0·2		5·3		0·3		6·1	0·3	5·3	0·3	0	0	1	0
16-31	5·9			0·1	5·6		0·2		5·9	0·1	5·6	0·2	0	0	0	1
TOTALS ...	137·1		0·3	3·1	131·7		2·2	0·9	142·2	5·9	135·6	5·2	1	1	14	13
MEANS ...	+ 5·7		− 0·1		+ 5·5		+ 0·1		5·9	0·2	5·7	0·2	...	...	...	...

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

TABLE 14.—*Mean errors E_1 and E_2 for 1928.*

BASSEIN

PERIOD 1928	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.	0·6 feet of height H. W.	L. W.
Jan. 1-15	11·8			0·8		7·7	0·3		16·4	0·8	14·3	0·4	3	0	20	0
16-31	11·6			0·4		11·5	0·4		17·9	0·5	17·0	0·4	6	1	9	4
Feb. 1-15	21·6			0·4		6·9	0·7		22·4	0·4	18·9	0·7	6	4	9	18
16-29	2·0			0·5		17·4	0·4		20·6	0·6	29·4	0·4	8	15	15	2
Mar. 1-15	14·8			0·5		10·0	0·6		18·3	0·6	23·2	0·6	5	8	11	11
16-31	6·0			0·3		15·0	0·6		15·5	0·5	27·0	0·6	4	8	8	12
April 1-15	14·9			0·5		0·8	0·5		18·6	0·5	19·9	0·5	4	6	10	4
16-30		13·1		0·7		30·7		0·0	16·1	0·7	30·7	0·2	6	14	18	0
May 1-15		14·9		0·6		27·3	0·3		17·0	0·6	27·6	0·4	4	11	13	6
16-31		20·7		0·2		32·3	0·5		21·2	0·2	32·3	0·5	8	17	0	9
June 1-15		10·7		0·7		11·5		0·2	18·4	0·7	14·0	0·3	7	2	17	2
16-30	12·2			0·6		23·6		0·5	14·2	0·7	23·6	0·7	3	11	19	12
July 1-15	8·1			0·2		14·2		0·3	13·1	0·2	17·0	0·3	2	0	1	4
16-31		1·7	0·0			19·6		1·4	10·5	0·4	19·8	1·4	2	6	4	29
Aug. 1-15		14·1	0·4			25·6		1·4	34·2	0·5	29·5	1·4	11	6	8	22
16-31		6·3	0·7			26·8		0·8	20·6	0·7	27·8	0·8	7	11	17	13
Sept. 1-15		7·4	0·7			22·8		1·0	15·8	0·7	23·4	1·0	4	12	15	14
16-30		8·9	1·1			34·1	0·8		20·5	1·1	34·3	0·9	5	16	19	19
Oct. 1-15		13·9	0·2			40·7		0·8	16·7	0·4	40·7	0·8	4	21	4	18
16-31		6·9		0·4		36·7		1·3	12·0	0·5	36·7	1·3	1	20	7	21
Nov. 1-15		13·4		0·9		46·0		1·3	14·7	0·9	46·0	1·3	4	24	27	22
16-30		10·1		0·4		29·4		0·0	18·6	0·4	29·4	0·4	6	14	6	5
Dec. 1-15		10·6		0·6		35·4	0·1		13·3	0·6	35·4	0·2	4	17	10	0
16-31	4·1			1·0		5·9		0·2	19·0	1·0	17·3	0·4	6	4	28	5
TOTALS ...	107·4	152·7	3·1	9·7		531·9	5·2	9·2	425·6	14·2	635·2	15·9	119	218	295	252
MEANS ...	− 1·9		− 0·3		− 22·2		− 0·2		17·7	0·6	26·5	0·7	...	..	...	..

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

TABLE 15.—*Mean errors E_1 and E_2 for 1928.*

PILAKĀT OR DESERTERS' CREEK

PERIOD 1928	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	22·4		0·2		16·2		0·2		22·4	0·2	16·2	0·4	2	3	0	0
16-31	30·4			0·1	27·5		0·4		30·4	0·4	27·5	0·5	13	14	0	3
Feb. 1-15	22·1			0·0	23·5		0·4		22·1	0·2	24·6	0·5	7	10	0	2
16-18	23·7			0·4	18·0			0·2	24·9	0·4	18·6	0·4	4	1	0	0
Mar. 1-15	A cargo boat collided with the observatory and clock stopped.															
16-31																
April 1-15	14·8			0·6	6·9		0·3		16·5	0·6	10·7	0·4	2	1	3	3
16-30	11·4			0·3		6·1		0·6	15·4	0·4	9·6	0·6	3	1	0	5
May 1-15	6·9			0·3	4·6		0·4		9·5	0·3	7·4	0·7	1	0	0	7
16-31	13·4		0·3			2·6	0·1		15·1	0·4	9·1	0·5	2	0	0	4
June 1-15	18·9			0·8	9·6			0·3	19·1	0·9	11·6	0·5	2	0	10	1
16-30	15·0			0·1	7·2			0·2	15·6	0·3	13·2	0·6	1	0	0	1
July 1-15	18·9			0·6	8·9		0·2		19·3	0·7	10·2	0·7	6	0	4	5
16-17	17·3			0·6	13·0			1·0	17·3	0·7	13·0	1·0	0	0	1	2
Aug. 1-15	Observatory damaged.															
†16-31	10·0			0·1	5·0		0·2		12·6	0·4	11·7	0·3	2	1	1	1
Sept. 1-15	5·7		0·3		0·2		0·3		9·9	0·3	7·5	0·4	0	1	0	1
16-30	2·6		0·2			3·0	0·4		8·5	0·4	9·0	0·6	0	0	0	3
Oct. 1-15		3·1		0·3		11·1		0·3	5·8	0·5	11·4	0·5	0	0	2	2
16-31		1·0		0·5		13·4		0·4	6·8	0·5	15·9	0·6	0	1	2	7
Nov. 1-15		9·0		0·2		14·3	0·2		10·4	0·4	14·3	0·5	2	2	0	3
16-30	1·3			0·1		11·7	0·4		5·0	0·4	15·9	0·6	0	4	1	5
Dec. 1-15		4·4	0·1			10·5	0·6		6·1	0·4	12·5	0·7	0	0	1	5
16-31	13·7			0·1		1·1	0·0		13·7	0·3	8·3	0·5	0	0	0	3
TOTALS ...	248·5	17·5	1·1	5·1	140·6	73·8	4·1	3·0	306·4	9·1	278·2	11·7	47	39	25	63
MEANS ...	+ 11·0		− 0·2		+ 3·2		+ 0·1		14·6	0·4	13·2	0·5	...	...	...	...

* E_1 is with regard to sign: E_2 is without regard to sign.
† Tide-pole observations from 16th August 1928.

TABLE 16.—*Mean errors E_1 and E_2 for 1928.*

RANGOON

PERIOD 1928	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		2·3	0·4			0·8	0·2		6·9	0·4	13·8	0·5	0	0	0	0
16-31	1·3		0·2		1·5		0·3		6·1	0·4	14·0	0·6	0	1	0	4
Feb. 1-15		0·3	0·2		0·7		0·3		8·9	0·3	15·1	0·5	1	2	0	0
16-29		5·1		0·0		4·8		0·1	9·3	0·4	12·0	0·5	1	1	1	2
Mar. 1-15		11·3	0·0		4·2		0·1		15·4	0·3	11·9	0·4	3	1	0	1
16-31		9·7	0·1			0·4		0·2	11·7	0·4	7·5	0·5	2	0	0	2
April 1-15		3·8		0·2	12·7		0·2		10·1	0·4	13·7	0·4	0	2	0	0
16-30		6·7		0·1		1·1		0·6	9·4	0·3	5·8	0·6	1	0	0	5
May 1-15		4·9	0·0		7·6		0·1		6·2	0·2	10·3	0·5	0	1	0	2
16-31		5·3	0·7			8·7		0·2	9·4	0·7	11·0	0·5	0	1	3	0
June 1-15		5·2		0·6	7·0			0·5	7·6	0·7	11·5	0·6	0	0	4	5
16-30		4·7		0·1		2·1		0·9	7·7	0·4	12·3	0·9	1	0	0	9
July 1-15		4·1		0·5		2·1		0·4	8·2	0·5	11·8	0·7	0	0	3	4
16-31		5·2		0·4	9·5			0·8	9·8	0·4	15·8	0·8	1	4	4	10
Aug. 1-15		13·7		0·3		1·1		0·3	13·8	0·5	11·6	0·4	2	0	1	0
16-31		6·9		0·1	1·6			0·0	10·4	0·4	11·5	0·3	1	0	0	0
Sept. 1-15		2·8	0·2			2·7		0·4	8·7	0·3	8·9	0·7	0	0	0	7
16-30		5·3	0·4		7·7		0·9		10·4	0·5	9·7	0·9	2	3	2	12
Oct. 1-15		3·0		0·0		3·6		0·1	7·1	0·5	6·2	0·3	1	0	1	1
16-31	8·7			0·2	1·2			0·4	11·5	0·3	12·2	0·8	1	1	2	8
Nov. 1-15		1·1	0·2			10·4		0·2	8·0	0·5	12·3	0·7	0	0	0	5
16-30	3·8		0·4			0·9	0·5		7·9	0·6	14·3	0·7	0	0	3	4
Dec. 1-15		5·2	0·3			0·2	0·9		8·2	0·5	11·1	0·9	1	0	0	7
16-31		2·7	0·2			0·5	0·1		5·6	0·3	13·9	0·5	0	0	0	4
TOTALS ...	13·8	109·3	3·3	2·5	53·7	39·4	3·6	5·1	218·3	10·2	278·2	14·2	18	17	24	92
MEANS ...	− 1·0		+ 0·0		+ 0·6		− 0·1		9·1	0·4	11·6	0·6	...	...	...	.

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

Chapter IV

GRAVITY AND DEVIATION OF THE VERTICAL

Section I

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

(i) Field Season 1928-29.

1. **Programme.**—The field season was planned to increase the number of gravity stations near the coast and in the south of India. Observations were made at twenty stations situated as follows:—

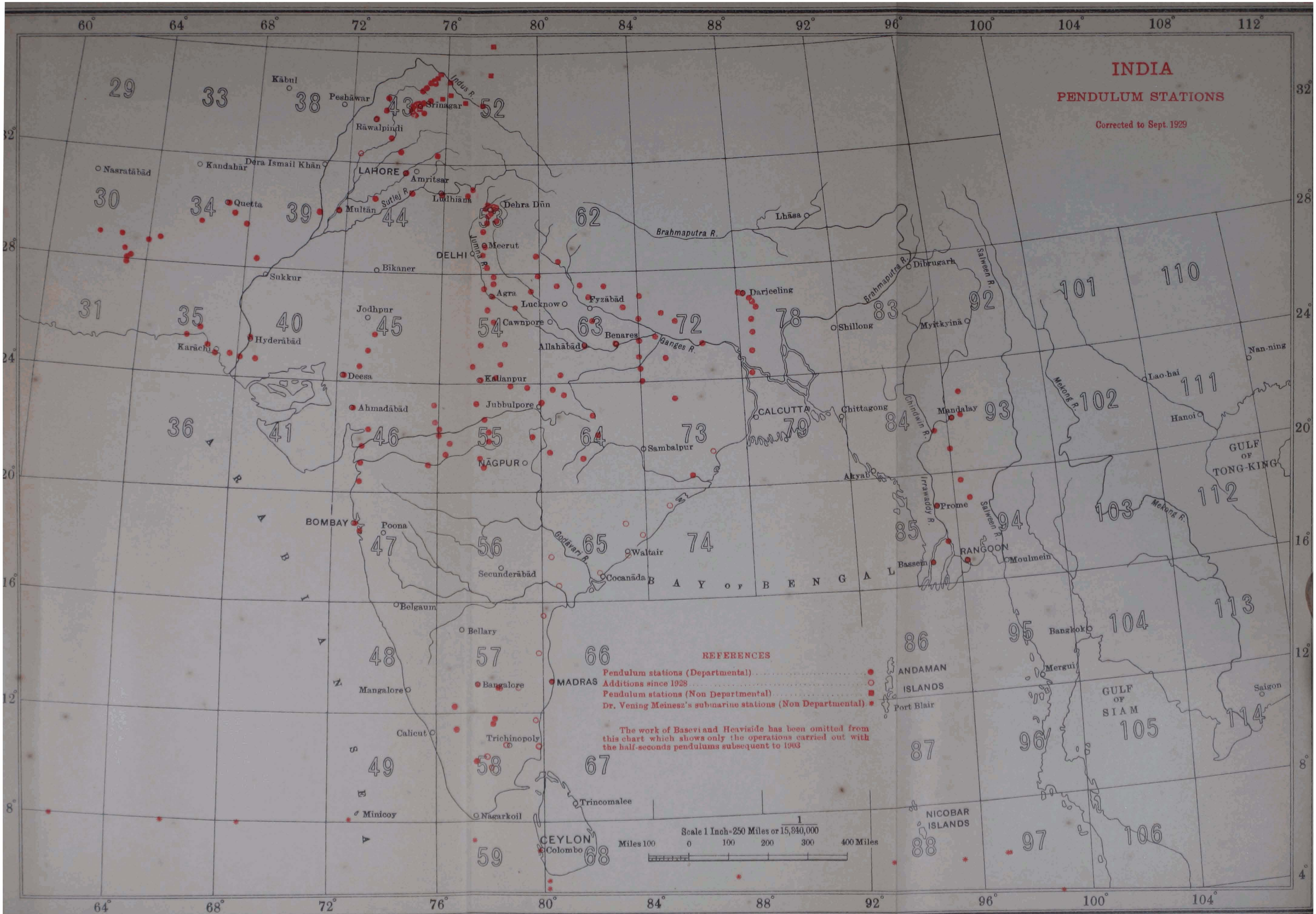
New stations	on or near the East coast	...	10
,, ,,	near the Eastern Ghāts	...	1
,, ,,	in Hyderābād State	...	1
,, ,,	in South India, inland	...	4
Old stations	... ...	...	4

At all stations, except Bahanagar Bāzār, where the pendulum tent was used, observations were made in rooms. The field season was ended early so as to swing pendulums at Dehra Dūn simultaneously with those of the Duke of Spoleto's Italian expedition to the Kara-koram.

2. **Strength of the party.**—The gravity party consisted of one officer, one clerk, one computer and eighteen khalāsis. Observations were made by Major E. A. Glennie. Movements were by rail. Health on the whole was good, although there was some malaria.

3. **Method of observation.**—The method of observation, and apparatus used was the same as in the previous field season, described in Geodetic Report Vol. IV. A Geryk type oil-filled vacuum pump was received early in the season and proved a great success and very light to work. After trying a great number of heavy greases, the most suitable grease for sealing the vacuum box was found to be Vacuum Oil Coy. product No. 2295, a very stiff tacky grease which keeps indefinitely without going rancid as do many of the heavy greases on the market.

4. **Adjustment of Riefler Clock.**—On return from the field the pendulum apparatus was put to a novel use. A reference to Geodetic Report Vol. III (Chapter 1, paras 6 & 7) shows that hitherto the Riefler clock has not been used for the reception of



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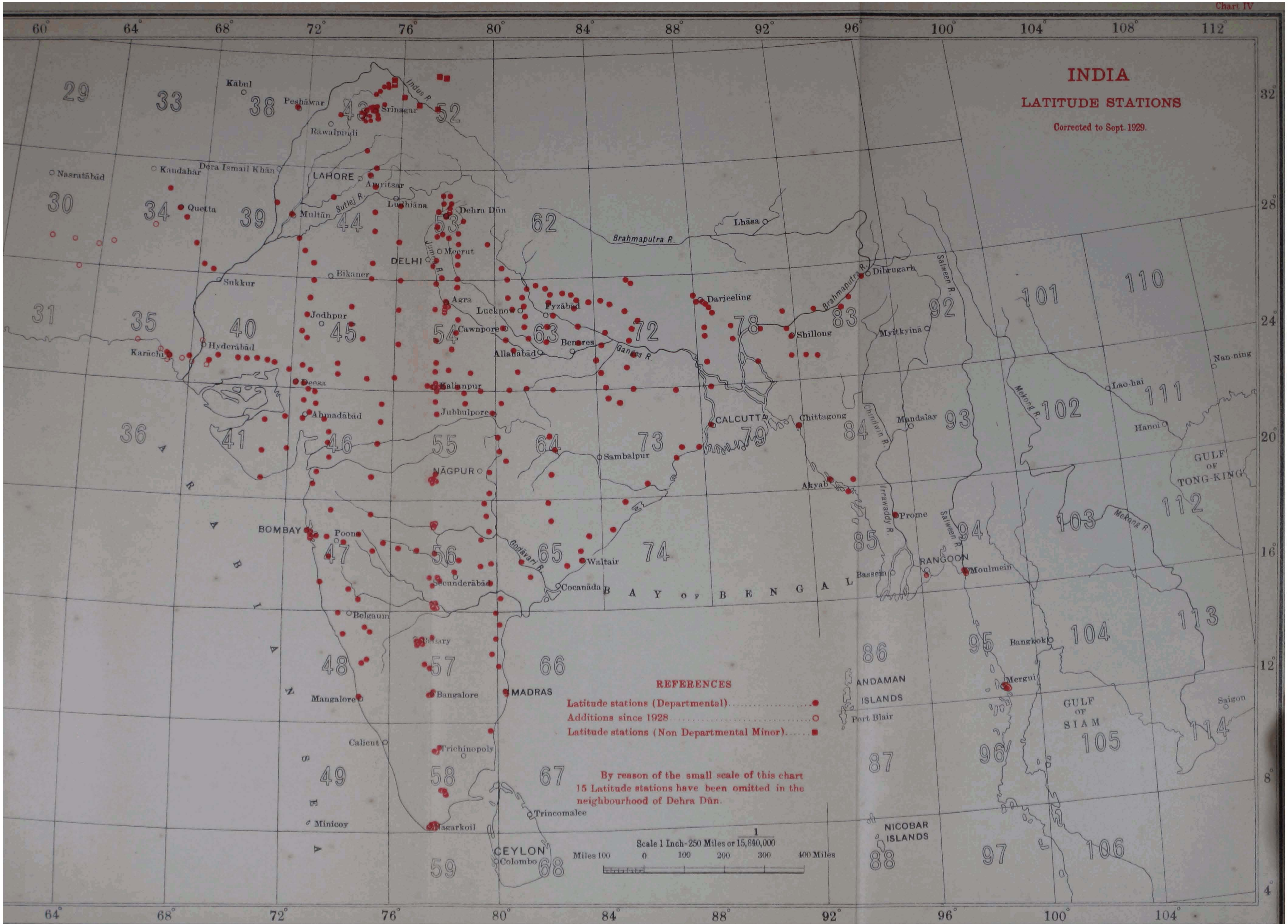
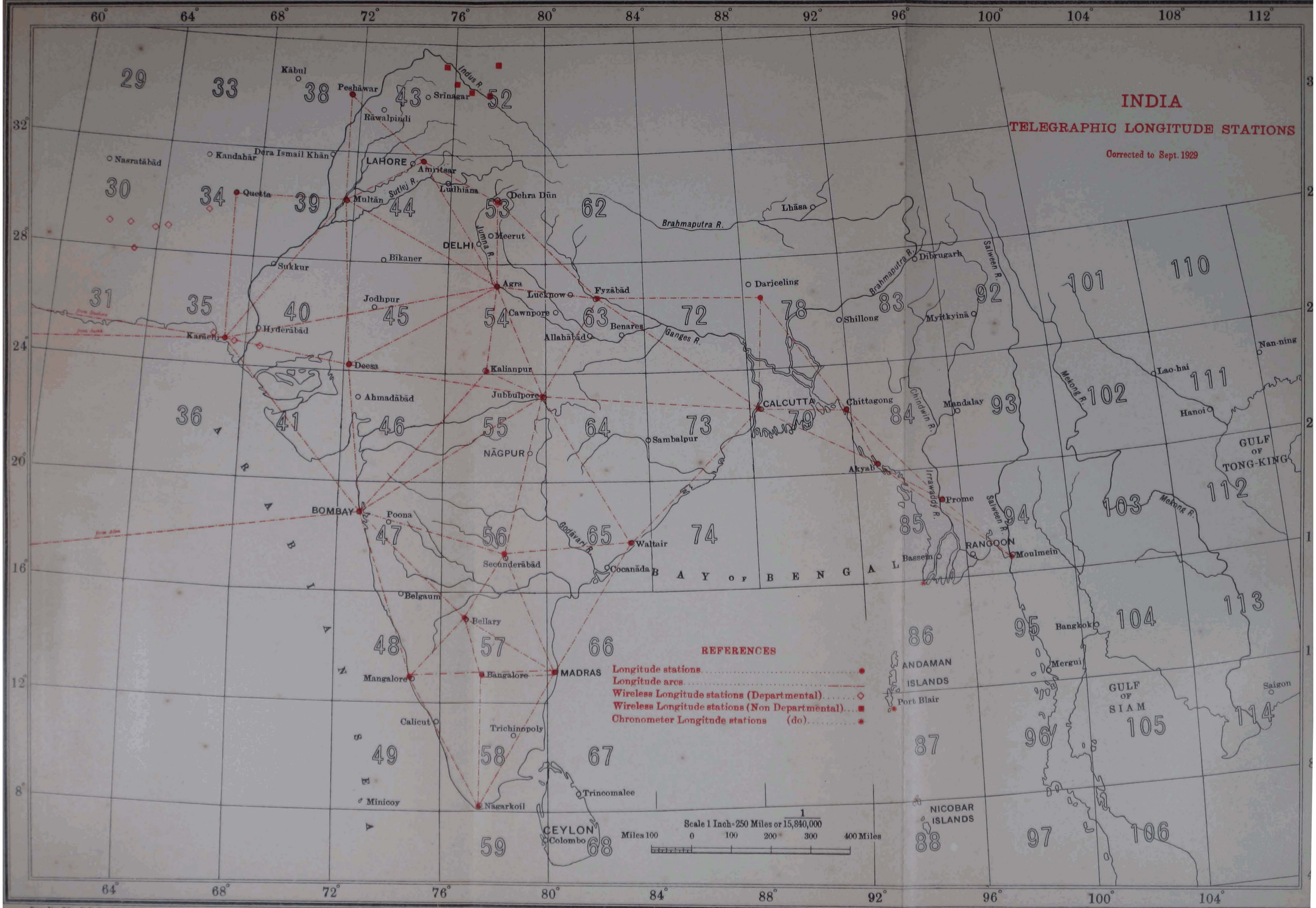

INDIA
LATITUDE STATIONS
Corrected to Sept. 1929.
REFERENCES
Latitude stations (Departmental)
Additions since 1928
Latitude stations (Non Departmental Minor)
By reason of the small scale of this chart 15 Latitude stations have been omitted in the neighbourhood of Dehra Dūn.
Scale 1 Inch = 250 Miles or 1/15,840,000
Miles 100 0 100 200 300 400 Miles
Kābul
Peshāwar
Srīnagar
Rāwalpindi
Nasratābād
Kandahar
Dera Ismail Khān
LAHORE
Amritsar
Ludhiāna
Quetta
Multān
Dehra Dūn
Meerut
DELHI
Bikaner
Sukkur
Agra
Lucknow
Fyzābād
Jodhpur
Cawnpore
Benares
Allahābād
Karāchi
Hyderābād
Deesa
Kalianpur
Jubbulpore
Ahmadābād
NĀGPUR
Sambalpur
CALCUTTA
Chittagong
Darjeeling
Shillong
Lhāsa
Dibrugarh
Myitkyinā
Mandalay
Akyab
Prome
RANGOON
Bassein
Moulmein
BOMBAY
Poona
Secunderābād
Waltair
Cocanāda
Belgaum
Bellary
Mangalore
Bangalore
MADRAS
Calicut
Trichinopoly
Minicoy
Nagarkoil
Trincomalee
CEYLON
Colombo
ANDAMAN ISLANDS
Port Blair
NICOBAR ISLANDS
Mergui
Bangkok
Lao-hai
Hanoi
Nan-ning
Saigon
GULF OF TONG-KING
GULF OF SIAM
BAY OF BENGAL
ARABIAN SEA
Indus R.
Sutlej R.
Jumna R.
Ganges R.
Brahmaputra R.
Godāvari R.
Chindwin R.
Irrawaddy R.
Salween R.
Mekong R.



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Heliozincographed at the Survey of India Offices, Dehra Dun.

wireless time-signals owing to the irregularity of its beats. The Riefler clock was made to actuate the pendulum flash-box and the flashes due to its beats observed. They came alternately in two series, each of which progressed fairly regularly across the field of view of the telescope. By a very slight adjustment of the levelling screws of the clock, without stopping it or interfering with the vacuum, the two series were reduced to one fairly even series. Complete regularity was not achieved; even with the best possible setting the beats of the Riefler clock are scarcely regular enough for satisfactory pendulum work; but this is a very delicate test. The small remaining irregularity of the beats is not noticeable when receiving the wireless signals. Since March 1929, therefore, the Riefler clock has been used to receive wireless time-signals and clock A is no longer used as an intermediary.

(ii) RESULTS OF THE FIELD WORK.

5. Details.—The results are shown in detail in Tables 1 to 4. Average heights for the Hayford corrections for zones beyond a radius of 20 miles were obtained from the "Average Height map of India" (*vide* maps in pocket at end of this volume).

6. Results at old pendulum stations.—These stations were revisited at the suggestion made by Dr. Oldham in 1926. He had doubts as to the stability of gravity at Dehra Dūn owing to its nearness to the Himālaya. The old and new values are shown below:—

Station	Old value of g	Date	New value of g	Date
	cm/sec²		cm/sec²	
Bilāspur ...	978·682	10- 1-10	978·681	3-11-28
Cuttack ...	978·660	14-12-04	978·659	19-11-28
Madras ...	978·282	5- 3-04	978·279	11- 1-29
Bangalore ...	978·026	2- 2-08	978·025	18 1-29

The observations at Madras in 1904 were not very consistent, (*vide* Prof. Paper No. 10, pp. 52 and 175). The agreement between new and old values is so good that it seems certain that gravity values in India are stable *inter se*. Whether they are stable in relation to gravity values in Europe is open to question. Each time a connection between Dehra Dūn and Europe has been made, a different value for g at Dehra Dūn has been obtained. These values are tabulated below:—

Date of observation at Dehra Dūn	European station of reference	g at Dehra Dūn
		cm/sec²
February 1904 ...	Kew	979·063
August 1913 ...	Genoa	079
March 1924 ...	Kew	054*
October 1927 ...	Cambridge	072
January 1929 ...	Kew	068*
February 1929 ...	Genoa	069

* The Dehra Dūn observations in 1924 and 1929 are related to a single set of observations at Kew in 1926.

Two other values may be deduced from observations at Jalpaigurī by Dr. Hecker in 1905, and at Colāba by Commander Alessio in 1906. In both cases the European station of reference is Potsdam. At Jalpaigurī the S. of I. observations referred to Dehra Dūn were done at the same time as those of Dr. Hecker, but at Colāba they were done in 1904, so the Colāba deduction has less weight. The deduced value of g at Dehra Dūn from these two stations is: from Jalpaigurī 979·065 and from Colāba 979·059 cm/sec^2. The value which has been adopted for Dehra Dūn throughout is 979·063 cm/sec^2.

7. Basevi stations.—The observation at Cocanāda gives one more comparison with the old work of Basevi. Up to date, eight Basevi stations have been revised in addition to Dehra Dūn. Details of Basevi stations referred to the Potsdam system are given in the Report of the International Geodetic Association for 1909, Vol. III, page 236.

Basevi's value for Dehra Dūn is 979·069 cm/sec^2. The difference in g between Dehra Dūn and the revisited stations is given below.

Difference in g from Dehra Dūn.

Station	Basevi	Modern	B-M
	cm/sec²	cm/sec²	cm/sec²
Cocanāda ...	− 0·796	− 0·781	− 0·015
Madras ...	− 1·035	− 1·017	− 0·018
Bangalore ...	− 0·586	− 0·571	− 0·015
Kaliānpur ...	− 0·310	− 0·286	− 0·024
Nojli ...	+ 0·083	+ 0·080	+ 0·003
Mussoorie ...	− 0·282	− 0·270	− 0·012
*Miān Mīr ...	+ 0·311	+ 0·320	− 0·009
Kaliāna ...	+ 0·074	+ 0·091	− 0·017

* At Miān Mīr Basevi used the light stand.

8. European stations of reference.—The fundamental gravity base station for all gravity work is at Potsdam in the pendulum hall of the Geodetic Institute. Here observations with a number of reversible pendulums were begun in 1898. The value of g obtained at Potsdam is $981 \cdot 274 \pm 0 \cdot 003$ cm/sec^2.

The values of g at the other European stations named in para 6 above are all derived from Potsdam. Brief details are given below; fuller details can be obtained from the following publications :—

(i) Report of the International Geodetic Association 1900.

(ii) U. S. Coast and Geodetic Survey Report 1901, Appendix 5.

(iii) Report of the International Geodetic Association 1909, Vol. III. (This report contains comprehensive lists of all gravity work).

Kew. $g = 981 \cdot 200$ cm/sec^2

Reference station	Potsdam
Observer	Putnam
Date	1900

Genoa. $g = 980 \cdot 518$ cm/sec^2

There are three links in the chain connecting Genoa to Potsdam, viz:—

Potsdam—Padua
Padua—Turin
Turin—Genoa

Cambridge. $g = 981 \cdot 265$ cm/sec^2

Reference station	Potsdam
Observer	Vening Meinesz
Date	1926

At the same time Lenox Conyngham obtained the same result for g at Cambridge using Kew as the reference station. The values of g at Kew and Cambridge, therefore, seem to be very well established.

9. Results at new stations.—At Bahanagar Bāzār the negative anomaly was unexpected as this is on an elevated part of the geoid. The alluvium is evidently very light in this area, whilst the geoid is raised by deep-seated material of high density.

At Waltair a rocky spur runs out to the coast. If this is not compensated the positive anomaly is explained.

The negative anomalies at Gūdūr, Vellore, and Cuddalore show that at Madras is not a purely local anomaly.

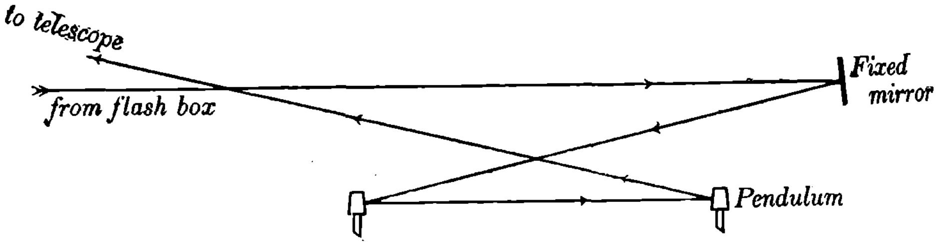
Other anomalies are in reasonable accord with the geoid.

(iii) FIELD OBSERVATIONS MADE DURING RECESS.

10. Shahpur (Sargodha) and Chakrata.—Observations were made at Shāhpur by Mr. B.L. Gulatee, M.A. in August 1928 at the request of the Punjab Irrigation Department, to supplement their gravimetrical investigations with the Eötvos Balance in this area. Gravity anomalies indicate a ridge of high density underlying Shāhpur and extending thence in a south easterly direction beyond Lahore.

Observations were made at Chakrātā in July 1929 by Major E. A. Glennie. The calculation of the orographical and Hayford corrections has been postponed until the new cantonment survey of Chakrātā has been completed.

The work at Chakrātā is interesting because it initiates a new method of observation with the Cambridge apparatus which will be adopted in future. The innovation consists in omitting the middle pendulum. The two outer pendulums are swung simultaneously with opposite phases as usual, and the flash from the flash-box travels as in the diagram below.



Thus one flash only, representing a combination of the two pendulums, is received in the telescope. This has the advantage that the two moving mirrors double the optical angle, so that satisfactory observations can be made with the pendulums swinging at a very small amplitude. The practical result of this is that the pendulums, which are very closely isochronous, can be swung continuously between wireless time-signals, thereby greatly reducing the labour of observation, and increasing the accuracy by almost complete elimination of clock errors. Observations were made with two clocks, viz:—the pendulum clock No. 238 by Strasser and Rohde, and a chronometer No. 12831 by Thomas Mercer. The Bordeaux transmission was used to rate one clock and the Rugby signals for the other.

The results at Shāhpur and Chakrātā are tabulated below :—

		A	B	C	Mean
Shāhpur	*s secs*	0·5078541	0·5078543	0·5078540	0·6078541
	g cm/sec^2	979·444	979·445	979·445	979·445

		½ (C + A)		½ (C + B)		Mean
		Mercer	S & R	Mercer	S & R	
Chakrātā	*s secs*	0·5080144	0·5080139	0·5080135	0·5080135	0·5080138
	g cm/sec^2	978·818	978·819	978·820	978·820	978·819

(iv) RESEARCH WORK.

11. The figure of the earth.—Although there are still some large areas in India untouched, the 184 gravity stations are sufficiently widely distributed to justify detailed investigation with regard to the figure of the Earth.

The value of gravity on a spheroid at any latitude is :—

$$\gamma_0 = G' (1 + A \sin^2 \phi - B \sin^2 2\phi)$$

where G' is the equatorial value of gravity,

A is a factor depending on the ellipticity,

B is 0·000006 in the case of spheroids applicable to the Earth (See "Geodesy", Dept. Paper No. 12, by de Graaff Hunter pp. 158-161).

The gravity data in India have been used to obtain the two unknowns G' and A with the result :—

$$G' = 978 \cdot 021 \text{ cm/sec}^2.$$

$$A = 0 \cdot 005359$$

which yields the value of the reciprocal of the ellipticity $1/\epsilon = 301$.

Now the spheroid which is most suitable for India is that which will best fit its geoid. This is the S. of I. spheroid I or II, $1/\epsilon = 292 \cdot 4$.

The gravity formula for this is :—

$$\gamma_0 = G' (1 + 0 \cdot 005234 \sin^2 \phi - 0 \cdot 000006 \sin^2 2\phi).$$

Here G' is the only unknown, so that a value for G' can be obtained from every observation of gravity. Chart VI shows values of G' averaged over two-degree zones of latitude for both S. of I. spheroid II* and the International spheroid ($1/\epsilon = 297 \cdot 0$), whose gravity equation is :—

$$\gamma_0 = G'(1 + \cdot 005287 \sin^2 \phi - 0 \cdot 000006 \sin^2 2\phi).$$

On the same figure are shown the heights of the "Compensated geoid" (*vide* para 12) for the same zones. The correlation between G' and the height of the geoid is most marked. This relation is well expressed by a simple straight line formula $G'_H = G'_0 + KH$

where K is a factor depending on the spheroid,

H is the height of the compensated geoid above the spheroid,

G'_0 and G'_H are the values of G' when H is zero and H respectively.

The gravity formula for a station on the geoid should therefore be :—

$$\gamma_H = G'_H (1 + A \sin^2 \phi - B \sin^2 2\phi)$$

$$\doteqdot \gamma_0 + KH$$

and the Hayford anomaly reduced to the spheroid is :—

$$g - \gamma_D \doteqdot g - \gamma_H + \text{Hayford correction}$$

$$\doteqdot g - \gamma_C - KH$$

The Bowie correction is included in the correction $-KH$. The height correction for the height of the gravity station above sea-level corrects gravity to the surface of the geoid. An additional correction

* a = 6,378,541 and $1/\epsilon = 292 \cdot 4$, See "Geodesy", Dept. Paper No. 12, by de Graaff Hunter, and Geodetic Report Vol. III, pp. 80-82.

is required to reduce to the surface of the spheroid. This is the Bowie correction and is equal to $+\cdot 094\,H/1000$ (See Geodesy p. 160). It will not exceed $0\cdot 003$ cm/sec^2 in Peninsular India. It must be emphasized that the correction $-KH$ has been obtained empirically from the data in Peninsular India. Its use therefore is strictly limited to Peninsular India; elsewhere conditions may well be entirely different.

The foregoing considerations show that in Peninsular India a satisfactory spheroid is not likely to be obtained from gravity data unless some correction similar to $-KH$ has first been applied to it.

When H is expressed in feet the values of G'_0 and K are:—

Spheroid	G'_0	K
	cm/sec^2	
S. of I.	978·025	0·0021
International	978·017	0·0019

Chart VII shows $g-\gamma_C$ using Helmert's formula of 1901, and Chart VIII shows $g-\gamma_D$ using this formula for gravity and the International spheroid for H.

At Jubbulpore KH amounts to $+\ 0\cdot 040$ cm/sec^2. Such an anomaly as this would be caused by a long ripple, a few miles in height, in the interface between the crust and the denser sub-crust, at a depth of (say) 70 miles. The crest of this ripple would underlie the highest part of the geoid, and run NW. from Sambalpur through Jubbulpore to Jodhpur. Northwards the trough would underlie the Gangetic Plain and to the south it would be under the depressed region of the geoid (Kārwār, Bellary etc.)

In the succeeding paragraphs reasons will be given for the belief that the main features of the geoid and of the gravity anomalies are due to deep-seated causes such as that outlined above. The argument is based on a critical examination of the geoids which will now be described.

12. The geoids.—The surface of a plastic, homogeneous Earth would as a result of its rotation assume the form of a spheroid. Since the figure of the Earth does in fact approximate to a spheroid, and since a spheroid is convenient for mathematical computation, it is universally adopted as the most convenient figure for the representation of the actual features of the Earth.

Land masses, ocean depths and lack of homogeneity of the crust cause deviations of the vertical from the true normal to the spheroid. Given a knowledge of these deviations a surface is obtained which rises and falls with reference to the spheroid. It represents the true mean surface of the sea itself, and in the case of land areas it is the surface of the water in small hypothetical canals imagined carried across in land from the sea. This surface is known as the GEOID.

If our knowledge of topography and crustal densities were complete, we could accurately compute the form of the GEOID by considering the attraction of the various masses. Our knowledge is faulty, but as a good starting point the theory of isostasy first propounded by Pratt and elaborated by Hayford is adopted. Put briefly, this theory states that all excess or deficient masses are compensated below sea-level: the compensation being uniformly spread out vertically until it is complete at a definite depth, "the depth of compensation", which is assumed to be about 70 miles. The ideal geoid computed on this theory is called the ISOSTATIC GEOID*. (See Chart IX, compiled by Captain G. Bomford, R.E.).

If the GEOID, derived from actual deviations of the vertical is corrected according to Hayford isostasy, i.e. if at any point on the GEOID the corresponding height of the ISOSTATIC GEOID is deduced from the height of the GEOID, a new figure is reached which is called the COMPENSATED GEOID†.

13. Deductions from the geoids.—A comparison of the compensated and isostatic geoids should indicate how far Hayford isostasy is correct. If there is some constant error in the assumptions made, applicable to the whole of the portion of the geoid under consideration, e.g. if compensation is only 50°/₀ complete over the whole of Peninsular India, the compensated geoid should still show a general similarity to the isostatic geoid. There is however no similarity at all. The form of the compensated geoid might be due to geological features of average density differing from that assumed in the computations. Here again the surface geology seems to be in no way responsible for its form. The contours of the compensated geoid run across geological formations of widely different densities without any corresponding change in shape. One is therefore forced to the conclusion that the main features of the compensated geoid are due to a hidden deep-seated cause.

14. The Hayford gravity anomalies.—Precisely the same deductions can be made from the gravity anomalies. The anomaly contours are very similar to those of the compensated geoid; indeed this follows as a necessary result of the correlation found between G'_{H} and H. Thus the major part of the gravity anomalies has the same deep-seated cause as the geoidal anomalies.

Local variations of density affect gravity more than they do the geoid. When therefore the correction KH, that is to say the correction for the anomalous deep-seated masses, has been applied to the Hayford gravity anomalies, the residuals or corrected anomalies $(g - \gamma_0)$ should portray the local geology much better than the uncorrected anomalies $(g - \gamma_C)$. If this is the case it will be a strong confirmation of the statement that the KH anomalies are due

* See Bulletin Geodesique No. 17, p. 30.

† See de Graaff Hunter, Geophysical meeting of the R. A. S., 20-4-28, and Geodetic Report Vol. III page 81.

to a deep-seated cause. In this connection, however, the corrected anomalies have one defect. When a geological formation of excessive or deficient density is of sufficiently wide extent to appreciably affect the geoid, *KH* will correct for it, so that in the middle of a wide area of high density $g-\gamma_D$ will tend to be too low and vice versa.

The table below gives a comparison of the indications provided by $g-\gamma_C$ and $g-\gamma_D$ at certain places where information as to the density of the underlying strata is available. The anomalies are with reference to the S. of I. spheroid II and the International spheroid.

Place	Latitude	Longitude	Density	S of I. Spheroid II		International	
				$g-\gamma_C$	$g-\gamma_D$	$g-\gamma_C$	$g-\gamma_D$
				*cm/sec*²	*cm/sec*²	*cm/sec*²	*cm/sec*²
Jālgaon ...	21° 00′	75° 34′	[a]	+ ·029	+ ·014	+ ·036	+ ·009
Ellichpur ...	21° 18′	77° 31′	[a]	+ ·042	+ ·022	+ ·050	+ ·012
Hoshangābād ...	22° 45′	77° 44′	2.6	+ ·036	− ·002	+ ·037	− ·011
Mortakka ...	22° 13′	76° 03′	2·67	+ ·013	− ·019	+ ·019	− ·021
Umariā ...	23° 32′	80° 54′	2·6	+ ·022	− ·005	+ ·032	− ·008
Damoh ...	23° 50′	79° 26′	2·7	+ ·025	− ·010	+ ·031	− ·015
Katnī ...	23° 50′	80° 26′	2·7	+ ·022	− ·005	+ ·032	− ·008
Bilāspur ...	22° 04′	82° 12′	2·62	+ ·022	− ·018	+ ·028	− ·008
Raipur ...	21° 14′	81° 41′	2·7	+ ·006	− ·026	+ ·015	− ·021
Cuttack ...	20° 29′	85° 52′	1·91	+ ·012	− ·030	+ ·021	− ·030
Madras ...	13° 04′	80° 15′	1·90	− ·042	− ·025	− ·038	− ·026
Mysore ...	12° 19′	76° 40′	2·85-2·90	− ·019	+ ·019	− ·008	+ ·030
Bangalore ...	13° 01′	77° 35′	2·85-2·90	− ·019	+ ·023	− ·010	+ ·030
Edgar Shaft ...	12° 56′	78° 16′	2·90-2·95	+ ·013	+ ·039	+ ·024	+ ·053

[a] Trap under a small depth of alluvium (i. e. fairly high density).

The information about densities was obtained from the Director of the Geological Survey of India in 1906 and 1910. He pointed out however that owing to the meagre information available, his estimates are rather in the nature of expert guesses, and must not be accepted as strictly accurate.

Bearing this in mind it is considered that in no case does $g-\gamma_D$ give indications which are definitely wrong, whereas $g-\gamma_C$ may be considered wrong at Hoshangābād, Umariā, Katnī, Bilāspur and Cuttack. The normal density assumed for Hayford computations is 2·67.

In the above table all except the last four places are on an elevated part of the geoid. Next season's gravity work will be all on a depressed part of the geoid, after which it is hoped to make a more detailed examination of the relation between gravity anomalies, the geoids and geology.

(v) DEVIATION OF THE VERTICAL.

15. Sind and Baluchistan.—The computation of the astrolabe work of field season 1927-28, which could not be completed in the following recess, has now been completed.

The personal equation apparatus described in Geodetic Report Vol. III was used for the first nine stations; it gave a good deal of trouble, and finally at Dālbandin failed owing to a mechanical defect. The average of the results for personal equation was taken and used for all stations. The corrections for personal equation so obtained were:—

E.A. Glennie	– ·01 secs.
B.L. Gulatee	– ·11 secs.

Results are shown in Table 5. The deflections in prime vertical have been omitted in the case of four stations at which there was a large difference in the results obtained on successive days. At the remaining stations also the P.V. deflections obtained differed more on successive days than the meridian deviations, and should be considered correct to the nearest second of arc only.

Chart XIII shows in black the uncorrected deviations referred to the Everest spheroid. Deviations obtained in previous years are also shown. They are numbered with the serial number given in Professional Paper No. 16, pages 174, 176 and 206.

All resultant deflections are in the direction of visible masses, and agreement with previous work is everywhere good, but the deflections at Sāhiji are remarkably large. At this place the resultant deflection points to an exposure of scarlet red soil in the cliff about 300 yards away. This red soil was not seen anywhere else in the neighbourhood. If it betrays the presence of a mass of heavy mineral, such as hæmatite, the deflection would be explained. Unfortunately no sample of this soil was collected. On the same chart are shown in red the Hayford deflection anomalies referred to S. of I. spheroid II. These anomalies are not inconsistent with an extension under this area of the deep-seated feature which raises the geoid in the northern part of Peninsular India. The red broken line indicates the approximate line of its crest.

TABLE 1.—*Times of vibration at Dehra Dūn. Season 1928-29.*

Date		A	B	CA	CB	Mean
1928		s	s	s	s	s
October	18	0·5079547	...	0·5079538	...	
	,,	9541	...	9541	...	
	,,	9547	...	9542	...	
	19	9534	0·5079534	...	...	
	,,	9527	9532	...	...	
	,,	9529	9540	...	...	
	20	...	9537	...	0·5079527	
	,,	...	9532	...	9547	
	,,	...	9550	...	9548	
	21	...	9538	...	9541	
	,,	...	9539	...	9542	
	,,	9536	9545	...	...	
	,,	9539	9548	...	...	
Mean		0·5079538	0·5079540	0·5079540	0·5079541	0·5079540

Date		A	B	CA	CB	Mean
1929		s	s	s	s	s
February	27	...	0·5079520	...	0·5079521	
	28	...	9531	...	9528	
	,,	...	9533	...	9523	
	,,	0·5079519	...	0·5079509	...	
March	1	9525	...	9522	...	
	,,	9525	...	9515	...	
	,,	9523	9530	...	...	
	2	9526	9536	...	...	
	,,	9534	9530	...	...	
Mean		0·5079524	0·5079530	0·5079515	0·5079526	0·5079524

Adopted Mean times of vibration.

	s	s	s	s	s
General Mean	0·5079531	0·5079535	0·5079528	0·5079534	0·5079532

TABLE 2.—*Difference between individual and mean pendulums. Season 1928-29.* (The unit is 10^{-7} sec.)

Name of station		A	v	B	v	CA	v	CB	v
Dehra Dūn	...	+ 2	0	0	+ 5	0	− 2	− 1	− 3
Bilāspur	...	− 2	− 4	− 2	+ 3	− 3	− 5	+ 6	+ 4
Bahanagar Bāzār	...	+ 6	+ 4	− 2	+ 3	− 3	− 5	+ 1	− 1
Cuttack	...	+ 4	+ 2	− 2	+ 3	− 4	− 6	+ 2	0
Chatrapur	...	+ 8	+ 6	− 1	+ 4	− 4	− 6	− 2	− 4
Dnsi	...	0	− 2	− 7	− 2	0	− 2	+ 9	+ 7
Pārvatīpuram	...	0	− 2	− 6	− 1	+ 3	+ 1	+ 5	+ 3
Waltair	...	− 2	− 4	− 7	− 2	+ 4	+ 2	+ 6	+ 4
Cocanāda	...	− 6	− 8	− 3	+ 2	− 1	− 3	+ 9	+ 7
Bezwāda	...	+ 1	− 1	+ 3	+ 8	− 5	− 7	+ 3	+ 1
Yellandlapād	...	+ 16	+ 14	− 8	− 3	+ 4	+ 2	− 13	− 15
Ongole	...	+ 5	+ 3	− 12	− 7	+ 10	+ 8	− 2	− 4
Gūdūr	...	− 1	− 3	− 4	+ 7	+ 3	+ 1	+ 2	0
Madras	...	+ 2	0	− 3	+ 2	0	− 2	+ 3	+ 1
Bangalore	...	− 3	− 5	− 10	− 5	+ 7	+ 5	+ 8	+ 6
Vellore	...	+ 2	0	− 3	+ 2	− 2	− 4	+ 3	+ 1
Cuddalore	...	+ 1	− 1	− 4	+ 1	+ 4	+ 2	+ 1	− 1
Negapatam	...	− 3	− 5	− 6	− 1	+ 3	+ 1	+ 6	+ 4
Trichinopoly	...	+ 7	+ 5	− 10	− 5	+ 10	+ 8	− 5	− 7
Dindigul	...	− 1	− 3	− 6	− 1	+ 7	+ 5	+ 2	0
Madura	...	− 3	− 5	− 5	0	0	− 2	+ 10	+ 8
Dehra Dūn	...	0	− 2	− 6	− 1	+ 9	+ 7	− 2	− 4
Mean	...	+ 2		− 5		+ 2		+ 2	

TABLE 3.—*Mean times of vibration and deduced values of g. Season 1928-29.*

Name of station		A	B	CA	CB	Mean
Bilāspur	s	0·5080523	0·5080523	0·5080524	0·5080515	0·5080521
	g	978·681	978·682	978·679	978·685	978·682
Bahanagar Bāzār	s	0·5080486	0·5080494	0·5080495	0·5080491	0·5080492
	g	978·695	978·693	978·690	978·694	978·693
Cuttack	s	0·5080575	0·5080581	0·5080583	0·5080577	0·5080579
	g	978·661	978·660	978·656	978·661	978·659
Chatrapur	s	0·5080648	0·5080657	0·5080660	0·5080658	0·5080656
	g	978·632	978·630	978·627	978·630	978·630
Dusi	s	0·5080854	0·5080861	0·5080854	0·5080845	0·5080854
	g	978·553	978·552	978·552	978·558	978·553
Pārvatīpuram	s	0·5080926	0·5080932	0·5080923	0·5080921	0·5080926
	g	978·525	978·524	978·525	978·528	978·526
Waltair	s	0·5080882	0·5080887	0·5080876	0·5080874	0·5080880
	g	978·542	978·542	978·543	978·546	978·543
Cocanāda	s	0·5081018	0·5081015	0·5081013	0·5081003	0·5081012
	g	978·490	978·492	978·491	978·497	978·492
Bezwāda	s	0·5081119	0·5081117	0·5081125	0·5081117	0·5081120
	g	978·451	978·453	978·447	978·453	978·451
Yel andlapād	s	0·5081145	0·5081169	0·5081157	0·5081174	0·5081161
	g	978·441	978·433	978·435	978·431	978·435
Ongole	s	0·5081254	0·5081271	0·5081249	0·5081261	0·5081259
	g	978·399	978·394	978·400	978·397	978·397
Gūdūr	s	0·5081485	0·5081488	0·5081481	0·5081482	0·5081484
	g	978·310	978·310	978·310	978·312	978·311
Madras	s	0·5081555	0·5081560	0·5081557	0·5081554	0·5081557
	g	978·283	978·282	978·281	978·284	978·282
Bangalore	s	0·5082225	0·5082232	0·5082215	0·5082214	0·5082222
	g	978·024	978·023	978·027	978·030	978·026
Vellore	s	0·5081771	0·5081776	0·5081775	0·5081770	0·5081773
	g	978·199	978·199	978·197	978·201	978·199
Cuddalore	s	0·5081641	0·5081646	0·5081638	0·5081641	0·5081642
	g	978·250	978·249	978·250	978·251	978·250
Negapatam	s	0·5081799	0·5081802	0·5081793	0·5081790	0·5081796
	g	978·189	978·189	978·190	978·193	978·190
Trichinopoly	s	0·5081862	0·5081879	0·5081859	0·5081874	0·5081869
	g	978·164	978·159	978·164	978·161	978·162
Dindigul	s	0·5082101	0·5082106	0·5082093	0·5082098	0·5082100
	g	978·072	978·072	978·074	978·075	978·073
Madura	s	0·5082021	0·5082023	0·5082018	0·5082008	0·5082018
	g	978·103	978·104	978·103	978·109	978·105

NOTE:—CA means C pendulum swung simultaneously with A pendulum.
CB " " " " " " B "
C pendulum is always in the front position in the Apparatus.

TABLE 4.—*Modern gravity observations in India.*
(Additions in field season 1928-29.)

No.	Sheet No.	Station	Date	Height	Latitude N.	Longitude E.	g	$g-\gamma_A$	$g-\gamma_C$
				feet	° ′ ″	° ′ ″	*cm/sec*²	*cm/sec*²	*cm/sec*²
167	43D	Shāhpur (Sargodha)	11 8 28	595	32 16 20	72 28 36	979·445	−0·001	+0·037
64*	64J	Bilāspur ...	3 11 28	878	22 03 53	82 12	978·682	+0·005	+0·013
168	73K	Bahanagar Bāzār	13 11 28	49	21 20 08	86 45 52	978·693	−0·015	−0·014
6*	73H	Cuttack ..	19 11 28	86	20 29 05	85 52 01	978·660	+0·006	+0·006
169	74A	Chatrapur ...	23 11 28	135	19 21 14	84 59	978·630	+0·046	+0·027
170	65N	Dusi ...	29 11 28	65	18 22 00	83 51 50	978·553	+0·016	−0·005
171	65N	Pārvatīpuram ...	5 12 28	388	18 45 20	83 18 40	978·526	−0·001	−0·007
172	65O	Waltair ...	12 12 28	137	17 34 30	83 16 50	978·543	+0·055	+0·020
173	65L	Cocanāda ...	18 12 28	11	16 59 00	82 14 40	978·492	+0·023	−0·006
174	65D	Bezwāda ...	24 12 28	65	16 30 19	80 37 46	978·451	+0·010	−0·002
175	65C	Yellandlapād ...	28 12 28	720	17 36 08	80 19 05	978·435	0·000	−0·013
176	66A	Ongole ...	2 1 29	119	15 29 57	80 02 42	978·397	+0·010	−0·008
177	57N	Gūdūr ...	5 1 29	49	14 08 36	79 50 53	978·311	−0·022	−0·045
2*	66C	Madras ...	11 1 29	20	13 04 08	80 14 54	978·282	−0·010	−0·050
40*	57G	Bangalore ...	18 1 29	3118	13 00 41	77 35 01	978·026	+0·026	−0·024
178	57P	Vellore ...	26 1 29	691	12 54 51	79 07 45	978·199	−0·024	−0·042
179	58M	Cuddalore ...	30 1 29	26	11 45 20	79 45 20	978·250	+0·009	−0·026
180	58N	Negapatam ...	5 2 29	15	10 46 57	79 50 50	978·190	−0·019	−0·057
181	58	Trichinopoly ...	9 2 29	267	10 47 58	78 40 46	978·162	−0·024	−0·040
182	58F	Dindigul ...	13 2 29	934	10 21 00	77 59 01	978·073	−0·035	−0·058
183	58K	Madura ...	17 2 29	435	9 55 34	78 08 24	978·105	−0·037	−0·058
184	53F	Chakrātā ...	3 7 29	6933	30 41 58	77 52 10	978·819	+0·096	...

* Old station revisited.

NOTE:—In Geodetic Report Vol. IV Page 66, the co-ordinates of Chandragup should have been given as λ 25° 26′ 02″·52 and L. 65° 49′ 44″·29, and of Gadāni as λ 25° 6′ 35″·6 and L. 66° 43′ 52″·4, in place of the figures given in that table.

TABLE 5.—*Deviations of the vertical. Field season 1927-28.*

Station	Observer	Height in feet	Everest's Spheroid: Geodetic Latitude	Everest's Spheroid: Geodetic Longitude	Everest's Spheroid: Deflection in Meridian	Everest's Spheroid: Deflection in Prime Vertical	International Spheroid*: Deflection in M	International Spheroid*: Deflection in P.V.	Topographical Deflection (Topography up to 400 miles) in M	Topographical Deflection (Topography up to 400 miles) in P.V.	Hayford Deflection in M	Hayford Deflection in P.V.	Hayford deflection anomaly: Everest in M	Hayford deflection anomaly: Everest in P.V.	Hayford deflection anomaly: International in M	Hayford deflection anomaly: International in P.V.
			° ′ ″	° ′ ″	″	″	″	″	″	″	″	″	″	″	″	″
Chandragup ..	B.L.G.	20	25 26 02·52	65 49 44·29	− 7·3	...	−14·3	...	−34·03	− 7·71	−6·65	+ 0·07	− 0·6	...	− 7·6	...
Gadāni ...	B.L.G.	67	25 06 35·6	66 43 52·40	− 1·5	+ 1·6	− 8·0	− 7·1	−24·40	−12·21	−2·65	− 3·65	+ 1·2	+ 5·3	− 5·3	− 3·4
Karāchi ...	B.L.G.	29	24 50 17·3	67 02 46·22	− 1·5	...	− 7·7	...	22·49	− 9·91	−2·60	− 1·24	+ 1·1	...	− 5·1	...
Sāhiji ...	E.A.G.	211	24 51 17·45	67 36 06·15	−13·9	+17·4	−19·8	+ 9·4	−19·24	− 6·61	−2·77	+ 0·11	−11·1	+17·3	−17·0	+ 9·3
Vikia ...	B.L.G.	47	24 41 50·87	68 03 39·01	− 1·3	...	− 7·0	...	−14·66	− 6·14	−1·16	+ 0·02	− 0·1	...	− 5·8	...
Kakcja ...	E.A.G.	33	24 42 54·89	68 34 25·96	− 1·3	+ 7·2	− 6·5	− 0·1	−11·50	− 6·52	−0·56	− 0·23	− 0·7	+ 7·4	− 5·9	+ 0·1
Hyderābād(Sind)	B.L.G.	41	25 22 59·33	68 21 16·93	− 0·8	...	− 6·2	...	−12·48	− 1·40	−0·87	+ 0·98	+ 0·1	...	− 5·3	...
Dālbandin ...	E.A.G.	2786	28 53 31·18	64 24 53·83	+ 3·6	+ 9·9	− 4·3	+ 0·6	−12·05	− 3·06	−2·30	+ 0·03	+ 5·9	+ 9·9	− 2·0	+ 0·6
Galugah ...	B.L.G.	1634	27 56 28·18	63 02 54·60	+ 1·8	+ 8·5	− 7·0	− 1·9	− 7·28	+ 4·05	+2·19	+ 2·05	− 0·4	+ 6·4	− 9·2	− 4·0
Nokkondi ...	B.L.G.	2281	28 49 33·71	62 44 42·48	−15·3	+15·0	−24·3	+ 4·4	−12·56	+ 0·76	−4·17	+ 0·41	−11·1	+14·6	−20·1	+ 4·0
Warechah ...	E.A.G.	2468	28 51 57·1	61 54 26·1	− 5·9	+12·8	−15·4	+ 1·9	− 5·16	+ 6·91	−0·02	+ 3·11	− 5·9	+ 9·7	−15·4	− 1·2
Yakmach ...	E.A.G.	2403	28 44 39·39	63 50 52·14	− 3·8	− 0·9	−12·0	−10·8	−15·48	− 4·71	−4·76	− 1·66	+ 1·0	+ 0·8	− 7·2	− 9·1
Nushki ...	E.A.G.	3339	29 32 27·30	66 02 43·20	+18·2	+10·0	+11·3	+ 1·9	− 7·72	−16·20	+1·45	−11·42	+16·8	+21·4	+ 9·8	+13·3

* With deflections at Kaliānpur origin of 5″·02 S. & 3″·17 W.
A plus sign indicates southerly or westerly deflections.

SECTION II

Development of Gravity Formulæ.

BY J. DE GRAAFF HUNTER, SC. D.

16. Rotating body nearly ellipsoidal.—It is easily shown that if a distribution of matter is such as to make the surface

$$r = c\,(1 + \sum_{1}^{n} U_n)$$

a level surface of its rotation about the polar axis and of its attraction, the value of the potential at an external point is

$$V = \frac{M}{r} \sum_{1}^{n} \frac{c^n U_n}{r^n} - \frac{\omega^2 c^5}{2r^3}(\tfrac{1}{3} - \cos^2\theta)$$

correct to first order terms: where

c = mean radius of the surface
M = mass of internal matter
U_n is a Laplace function of order n, small compared with unity.

From this it follows that the value of gravity at the level surface is

$$g_1 = G'\left\{1 - \tfrac{5}{2}m(\tfrac{1}{3} - \cos^2\theta) + \sum_{2}^{n}(n-1)U_n\right\} \qquad \ldots \quad (1)^*$$

where mG' is the centrifugal force at the equator.

The ellipsoid with mean meridian ellipticity [redacted]ial ellipticity 1/2C, [redacted]

Correction* to Geodetic Report Vol. V, Chapter IV, Page 64, Table 5—

Deviations of the Vertical.

"*Substitute* the following for the columns so headed".—

Station	International Spheroid Deflection in M	International Spheroid Deflection in P.V.	Hayford deflection anomaly International in M	Hayford deflection anomaly International in P.V.
	″	″	″	″
Chandragup ...	− 4·4	...	+ 2·3	...
Gadāni ...	+ 1·3	− 5·1	+ 3·9	− 1·4
Karāchi ...	+ 1·3		+ 3·9	...
Sābiji ...	−11·1	+11·3	− 8·3	+11·2
Vikia ...	+ 1·4	...	+ 2·6	
Kakeja ...	+ 1·4	+ 1·7	+ 2·0	+ 1·9
Hyderābād (Sind)	+ 2·1	...	+ 3·0	...
Dālbandin ...	+ 7·7	+ 1·8	+10·0	+ 1·8
Galugah ...	+ 5·7	− 0·4	+ 3·5	− 2·5
Nokkondi ...	−11·3	+ 5·9	− 7·1	+ 5·5
Warechah ...	− 1·9	+ 3·2	− 1·9	+ 0·1
Yakmach ...	+ 0·2	− 9·2	+ 5·0	− 7·6
Nushki ...	+22·8	+ 2·9	+21·3	+14·3

*These corrections have not been incorporated in Chart XIII.

in which $a = c\left(1 + \frac{1}{3}\epsilon\right)$, h = height above ellipsoid

$$A = \tfrac{5}{2}m - \epsilon - \tfrac{17}{14}m\epsilon \qquad B = \tfrac{\epsilon}{8}(5m - \epsilon).$$

For a figure not truly ellipsoidal *, represented by

$$r = a\left(1 + v_2 + v_4 + \sum_1^n u_n\right) \quad \ldots \quad \ldots \quad (4)$$

equations (1) and (3) show that gravity is

$$g_3 = g_2 + G'\sum_2^n (n-1)u_n \quad \ldots \quad \ldots \quad (5)$$

Green's theorem extended shows that the system may be replaced by a rotating solid ellipsoid† given by (2), with a skin distribution density of magnitude

$$\sigma = \frac{G'}{4\pi k}\sum_2^n (n-1)u_n = \frac{\Delta c}{3}\sum_2^n (n-1)u_n \quad \ldots \quad (6)$$

placed on the actual geoid, in which k is a gravitation factor, and Δ is the mean density of the earth. The distribution may be regarded as an equivalent to the anomalies.

The potential corresponding to this is

$$\delta V = \frac{M}{r}\sum_2^n \frac{c^n u_n}{r^n} \quad \ldots \quad \ldots \quad (7)$$

and the geoid rises as a result by H_0, where $H_0 = c\sum_2^n u_n$ ... (8)

17. Condensation of crustal anomalies on the surface.—The surface density σ is hypothetical, being an infinitely thin layer of infinite density. It is possible to replace it by physically possible volume densities in an infinity of ways.

As an example consider a volume distribution in which the density (nearly) constant in any vertical column is defined by

$$\rho = \frac{G'}{4\pi k}\Sigma\,(n-1)\,Z_n\left(\frac{r'}{r}\right)^n$$

where Z_n is a Laplace function of order n: and let the distribution be considered to extend between $r' = (1 - F_1)c$ and $(1 - F_2)c$. For this consideration we may treat the approximately spheroidal surface as a sphere. Using (7) it is clear that

$$\delta V = \int_{c(1-F_1)}^{c(1-F_2)} \frac{M}{r}\frac{r'^n}{r^n} Z_n\, dr'$$

$$= M\Sigma\frac{Z_n}{n+1}\left\{\left(1-F_2\right)^{n+1} - \left(1-F_1\right)^{n+1}\right\}\left\{\frac{c}{r}\right\}^{n+1}$$

* To take account of Darwin's deviation from spheroidal form, which forms the basis of Helmert's later formula, it is necessary to increase A by $-\frac{3}{7}f$ and B by $-\frac{3}{4}f$, where $f = -10^{-6} \times 2{\cdot}05$.

† This ellipsoid has total mass M, distributed in any way which makes the bounding ellipsoid a level surface of its own attraction and rotation.

and this is the same as that due to σ if

$$\frac{(1-F_2)^{n+1}-(1-F_1)^{n+1}}{(n+1)(F_1-F_2)}DZ_n=u_n \quad \dots \quad (9)$$

where $D=(F_1-F_2)c=$ thickness of the distribution.

Put $F_1=f+\frac{1}{2}\delta f$, $F_2=f-\frac{1}{2}\delta f$, and $\Delta f=\delta f/2\,(1-f)$.

Then (9) may be written

$$\frac{u_n}{DZ_n}=(1-f)^n\left\{1+\frac{n(n-1)}{\underline{|3}}\Delta f^2+\frac{n(n-1)\,(n-2)\,(n-3)}{\underline{|5}}\Delta f^4\right\} \quad (10)$$

which shows that for sufficiently small values of fn $u_n=DZ_n$, and the distribution through a finite thickness causes little change. In other words gravity anomalies at the surface can give little information as to the mean depth or vertical distribution of the density anomalies of long period.

The second factor in the right hand side of (10) shows the effect of uniform distribution about a mean depth. Thus for a uniform distribution through a depth of 70 miles, as in Hayford's compensation, for which $\Delta f = 1/113$, the result is only 10°/$_0$ different from that due to concentration at the mean depth of 35 miles if $n-\frac{1}{2} \doteq 113\sqrt{\frac{6}{10}}$ or $n = 87$, showing that this vertical distribution is relatively unimportant for features of extent $24800/2\times 87$, say 140 miles or less. Consequently gravity anomalies in such cases cannot distinguish between various distributions about a mean depth. For $n=87$ and $f=1/113$, however, $(1-f)^n = \cdot 46$, showing a great difference between surface distribution and distribution at a mean depth of 35 miles. For this mean depth to have no more than 10°/$_0$ effect, n must be kept less than 11, corresponding to a feature of some 1,000 miles in extent. For convenience of reference values of u_n/DZ_n are tabulated for various values of n.

Values of u_n/DZ_n.

	Mean depth 35 miles		Mean depth 40 miles	
n	At 35	Between 0 and 70	At 40	Between 10 and 70
10	·915	·914	·903	·900
50	·641	·666	·605	·603
100	·411	·467	·366	·398
300	·070	·186	·049	·101
500	·012	·113	·007	·021

The table indicates how large an anomaly is required for features of 25 miles extent ($n=500$) if this is distributed between depths of 10 and 70 miles — more than 5 times as much as if the distribution extends downwards from the surface.

It seems reasonable to attribute such equivalent hypothetical surface anomalies to density anomalies at a small depth, above the level at which the earth may be considered plastic. The dividing point between shallow and deep anomalies however cannot be derived from geodetic evidence alone.

18. Corrections for topography.—The formulæ of § 16 are for a figure whose matter lies entirely within the level surfaces concerned. In the case of the earth allowance must be made for topography external to the geoid.

The effect of this external topography on both the geoidal rise and the force of gravity can be calculated. Starting with belief in a certain degree of regional compensation, and also for computational convenience, we may combine with each feature a corresponding negative mass of equal amount at or below the geoid. It is at present undecided as to whether this should be done by means of a concentrated skin distribution in keeping with the quantity σ already employed. In doing so it is feasible to take the compensation on a regional basis, that is, with each vertical element of topography to associate a disc of compensatory negative skin density of any chosen radius. Whatever is finally decided in this respect, the effect on (5) may be denoted by δg_t and on (8) by δH_t, and these equations may be replaced by

$$g_4 = g_2 + \delta g_t + G' \sum_2^n (n-1)\, u_n \qquad \ldots \qquad (11)$$

$$H_0 = \delta H_t + c \sum_2^n u_n \qquad \ldots \qquad (12)$$

It is to be remembered that in g_2 the quantity h is the height above the ellipsoid. This may be replaced by

$$h' + H_0 - \delta H_t = h \qquad \ldots \qquad (13)$$

so that

$$g_2 = G' \Big\{ 1 + A \sin^2\phi - B \sin^2 2\phi + C \cos^2\phi \cos 2(\lambda - \lambda_0) - \frac{2}{a}(h' + H_0 - \delta H_t)\Big(1 + \epsilon + m + 3\sin^2\phi\,(\tfrac{5}{6} m - \epsilon)\Big)\Big\} \qquad (14)$$

In this h' is the *height above the geoid.*

The anomaly σ is now to be regarded as placed on the corrected geoid whose form is denoted by (12).

19. Relation between deflections and gravity anomalies.—It is to be noted that if the form of the geoid is known from deflection results, then theoretically (12) allows u_n to be determined, and (11) expresses the corresponding value of gravity; alternatively if the gravity anomalies are known, u_n can be found therefrom. In practice however the observational results are incomplete, and the best use must be made of available deflections and g anomalies. These latter give directly the local crustal equivalent anomaly at any place where g has been observed; which in itself is a satisfactory result to arrive at. In so far as these crustal anomalies exist, the particular form of compensation assumed as a basis of computation (see § 18 above) is disproved: it is none the less a useful standard of reference.

20. Major Glennie's relation.—In Section I of this chapter Major Glennie suggests a linear relation between the gravity anomalies found in India and the rise of geoid. This implies that

$$G' \sum_2^n (n-1)\, u_n - \frac{H_0 - \delta H_t}{a}\, 2G' \doteqdot -K(H_0 - \delta H_t) = K a \sum_2^n u_n \ldots \quad (15)$$

a result which cannot be strictly true, unless only one harmonic exists, when the equation becomes

$$n - 1 = -\left(K - \frac{2G'}{a}\right)\frac{a}{G'}$$

The value found by Major Glennie for K (in terms of the International spheroid) is $\cdot 0019 = \cdot 0017 + \frac{2G'}{a}$

$$\text{Hence } n - 1 = \frac{\cdot 0017 \times 2\cdot 09 \times 10^7}{0\cdot 978 \times 10^3} = 36\cdot 3$$

$$\text{or} \quad n = 37\cdot 3$$

which corresponds with an average angular period of $360/n = 10°$. An examination of the geoid in India (deduced from deflections) shows a rough periodicity in angular amount 12°. To this figure would correspond a value of $K = \cdot 0016$, which goes some way to explain the empirical result. More precise analysis of the geoid might perhaps bring about a closer accord; on the other hand Major Glennie's value may be modified when deduced from a more fully distributed set of gravity observations.

Without doubt the geoidal features represented by the lower harmonics are due to anomalies of density of great extent; and it seems reasonable to suppose that a very considerable portion of these lies at some considerable depth, such as 50 miles. In considering the local anomaly at a station of observation, interest centres on the anomalies close to the surface, i.e. within the reach of mines. From this point of view then it may be of interest to remove from the anomalies, reckoned from the spheroidal formulæ, the effect due to the generalised crustal anomalies found from the geoid as determined from deflection results. The residual anomaly is then more localised and likely to be of industrial interest. This process may be carried out without the harmonic analysis of anomalies, much more completely than by the application of Major Glennie's empirical term, which really hinges on the geoid being capable of representation by the 37th spherical harmonic. Captain Bomford has computed the crustal anomalies which will account for the geoid's form in India: and therefrom the corresponding gravity anomalies follow immediately. The difference between these and the actual anomalies found by gravity observations, appear to be quantities of industrial interest.

Section III

by Captain G. Bomford, R.E.

21. Summary.—From the shape of the Indian geoid a set of mass anomalies are deduced, which would be competent to explain the shape of the geoid. Although these masses cannot be uniquely determined, the solution given is considered to be a minimum solution: no other possible set of anomalies could have a total mass much smaller than that now given. The anomalies found are both intense and extensive; but, while they give definite disproof of the accuracy of the usual Hayford system for computing compensation, they do not definitely disprove the existence of regional hydrostatic equilibrium.

The Indian isostatic geoid has been computed, and is compared with the actual geoid. The lack of resemblance between the two surfaces gives further proof of the inaccuracy of the Hayford system in India.

No system is proposed as an alternative to Hayford's.

The probability of a correlation between geological surface densities and the expression $g - \gamma_D$ (introduced by Major Glennie in para 11 of this chapter) is examined. It is concluded that in India the correlation is not likely to be finally established.

A table is given to facilitate the computation of the geoidal rise due to different masses; such a table is required for the computation of the isostatic geoid.

22. Anomalies deduced from geoid.—The compensated geoid (see para 12) is an equipotential surface of the standard spheriod * and of the anomalies or departures from Hayford's hypothetical mass distribution. A knowledge of the form of one equipotential does not suffice to determine the masses to which it is related, but in the present case the problem may be simplified by the assumption that the anomalies occur reasonably near the surface † (say within 70 miles), and, if this depth is two or three times smaller than the horizontal extent of the main features, further knowledge of their depth is comparatively unimportant. An infinity of possible solutions still remains, but if a solution is found in which the distribution of the anomalies is in obviously close relationship to the

* The standard spheroid is the surface chosen as reference spheroid filled with matter, whose total mass equals that of the Earth, and which is distributed in such a manner that the bounding spheroid is also an equipotential, modified only by Darwin's depression of 10 ft. in latitudes 45° N. and S.

† For at great depths the Earth may be presumed to lack the strength necessary for the continued existence of an anomaly.

contours of the equipotential which they are required to produce, that solution will to some extent be a measure of the minimum total* mass of the anomalies. For instance, a local elevation of the Indian geoid of specified height and shape can be caused by a suitable distribution of mass beneath it. It could also, conceivably, be caused by a suitable distribution of positive and negative masses in France, or any other part of the world, but this second distribution would involve very much larger masses than the first, and would involve practical impossibilities.

Working on this basis, that the anomalies are to be as small as possible, a solution has been found by trial and error. The spheroid adopted is the International spheroid, so oriented, as regards its deflections at the origin, as to make the best possible fit with the Indian compensated geoid. (See Chart XII). As a first aproximation the country was divided into blocks 150 by 150 miles in horizontal extent, each containing a mass anomaly proportional to the mean height of the geoid overlying them, distributed through a depth of 70 miles. The total potential of these masses was calculated at 14 points typifying the geoid, and thence was found the height of the geoid at these points. The masses were then modified, and after a few trials the geoid was approximately fitted.

The 150 by 150 mile blocks were then broken up into 50 by 50 mile blocks, and the process was repeated, the geoid being fitted at 56 points. After repeated trials a solution was found such that the geoid was correctly fitted within two or three feet at each of these pionts.

Chart XIV shows the resulting mass anomalies, the 50 mile blocks being replaced by contours of equal mass per unit area. The unit employed is the mass of a layer of rock (density 2·67) one foot thick, and the contours are at 1000-foot intervals. It may be repeated that the geoid, as obtained from deflections in India, is an equipotential surface of the standard spheroid *plus* the actual topography (assumed to be of density 2·67) *plus* Hayford compensation *plus* these anomalies.

The intensity and extent of the anomalies is very considerable. Thus, in the Gangetic plain there is an area of 100,000 square miles in which the anomaly is equivalent to between −1,000 and −6,700 feet of rock; north of Nāgpur there are 50,000 square miles in which the anomaly is between +1,000 and +3,700 feet.

The above figures are only measures of the failure of isostasy in India, if the Hayford system is interpreted in its narrowest sense, namely that all surface rocks are of density 2·67, that the proper compensation is evenly distributed between ground level and a depth of 70 miles, and that it lies vertically under the feature which it compensates. More broadly the principle of isostasy may be taken

* Without regard to sign.

to mean that areas of reasonable size stand in hydrostatic equilibrium, and in this broader sense the failure of isostasy is not so clearly established. Thus the 25-foot elevation of the geoid north of Nāgpur would be accounted for if in the 50,000 square miles concerned the superficial rocks were 10% overdense for a depth of 10 miles, even though this excess was compensated throughout the next 60 miles. If the excess density covered 250,000 square miles, a thickness of 40,000 feet would suffice.

In the same way the depression in the Gangetic plain requires for its explanation an even greater thickness of low density sediments, greater, not only because the geoidal depression is rather more than 25 feet, but because it is closely adjacent to the apparently overdense Himālaya on the north: the defect in the plains has to counteract the tendency of this excess to raise the surrounding geoid.

Thus, although the Indian geoid offers considerable disproof of the accuracy of Hayford's detailed system, yet it does not offer positive disproof of regional hydrostatic equilibrium in a broad sense. At the same time it cannot be said that deductions from the Indian geoid contribute anything towards the proof of isostasy: on the contrary, the geodetic facts are only brought in line with the isostatic principle, in its broadest sense, by assuming the existence of very extensive abnormal rock densities of which there is no other evidence.

23. The isostatic geoid.—In a recent publication* Dr. Bowie has stated "The proof of isostasy has made it possible to compute an approximate geoid without all these (pendulum and deflection) observational data". The geoid so computed has been called the isostatic geoid by the Gravity Commission of the Geodetic and Geophysical Union. The Indian isostatic geoid is shown in Chart IX. The lack of resemblance between it and the actual geoid, as shown in Chart X, is a measure of the success of the computation. A geoid calculated on the assumption of no compensation at all would, of course, be still less successful, but Chart IX cannot be described as a useful approximation to Chart X. So far as is known, geoids of large areas based on observational data have only been drawn in the United States† and in India‡. In the second of these areas Dr. Bowie's proposed computation gives no useful approximation: in the U. S. it probably does better, for that is a less anomalous country than India. But until geoids have been drawn in many other countries, and unless the isostatic geoid is then found to be a fair approximation to the true geoid in those countries, it is not possible to accept the statement that the isostatic computation is a useful substitute for observational data.

The above criticism of Hayford's system does not imply that that system can be improved on. Some simple and well defined system is essential as a standard, and no alternative system is now suggested.

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* American Journal of science. No. 81, Sept. 1927.
† Hayford "Figure of the Earth and Isostasy".
‡ de Graaff Hunter. Survey of India "Geodetic Report", Vol. I.

24. Gravity deduced from geoid.—At any point it is easy to compute the vertical attraction of the anomalous masses deduced from the geoid in para 22. This has been done, and the result is exhibited in Chart XV. If the method of computing the anomalies was perfect, these attractions would everywhere be equal to $g-\gamma_C$, the usual Hayford anomaly based on pendulum observations, as shown in Chart VII. Inspection of Charts VII and XV shows that there are some very material differences. At any station let this difference, $g-\gamma_C$ *minus* the value deduced from the geoid, be designated E, so that E = Chart VII – Chart XV. Then ideally E should always be zero.

This quantity E is analogous to Major Glennie's $g-\gamma_D$ (para 11 of this chapter), the difference being that $g-\gamma_D$ is implicitly based on the assumption that the geoid can be fairly represented by a single spherical harmonic, whereas E is based on a mass distribution which, although many assumptions are involved in its choice, would at least produce the general outlines of the actual geoid. On these grounds it is thought to have some advantage over $g-\gamma_D$ as a basis for further discussion, although the sources of error described below (some of which apply to $g-\gamma_D$ with equal force), are such that this advantage may be more apparent than real.

Reasons why E is not everywhere zero are as follows:—

(*a*) The choice of an unsuitable reference spheroid. The magnitude of the anomalies deduced from the spheroid depends vitally on the height of the geoid above the spheroid of reference; a different spheroid of reference, or a change in the accepted deflections at the origin, will produce a different set of anomalies, and different values of their vertical attractions. But $g-\gamma_C$ is much less sensitive to a change of spheroid, so that the value of E will vary considerably, according to the spheroid used. On these grounds E may form a suitable basis for investigation of the Earth's figure. If it tends to be positive in some areas and negative in others, the accepted spheroid may be modified so as to lessen these inconsistencies. This computation has not been carried out in India: on account of the comparatively limited area of the gravity survey the weight of the result would not be comparable with that of spheroids obtained by more usual methods.

(*b*) The effect of unexplored areas outside the survey. It is noticeable, for example, that the geoid is raised in the extreme south of India, and that the deduced anomalies are positive, whereas $g-\gamma_C$ is negative; hence a large value of E. The apparent rise of the geoid may be due to a bad choice of spheroid, or it may be due to unmeasured positive anomalies in Ceylon and the neighbouring ocean. It is doubts of this kind which, for the purpose of finding the figure of the Earth, restrict the utility of E to very large areas of survey.

(*c*) Local anomalies. A very localised excess of density may cause a large positive value of $g-\gamma_C$, but it will have little effect on the shape of the geoid, and it will not be reflected in the attractions deduced therefrom. Consequently E will be positive.

(*d*) Ambiguity in the process by which the anomalies are deduced. For example, a small feature of the geoid, such as the spur of high density near Bombay, may be caused by an intense excess of mass in a small area, or by a less intense excess in a larger one. Unless the shape of the geoidal contours is known in detail the distribution of the anomalies is quite arbitrary, and since their vertical attraction depends more on their intensity than on their horizontal extent, a large value of E may result. Further, the vertical distribution of the anomalies may not be as postulated.

(*e*) The geoid is based on a limited amount of observational data. Its contours may be imperfectly drawn.

As a measure of the effect of these various sources of discrepancy, it may be noted that at individual stations the mean value of E is very little less than that of $g-\gamma_C$. But if local and marginal effects are eliminated by the meaning together (with regard to sign) of all the values of E in fairly large areas, the discrepancy is considerably reduced. Thus in all 4-degree squares in which 8 or more gravity stations exist, this mean averages only ·005, compared with the figure of ·015 for the means of $g-\gamma_C$.

25. Correlation with Geology.—In para 14 Major Glennie has brought forward a correlation between his $g-\gamma_D$ and the density of the surface rocks. It is obvious that, if the rocks underlying one of two neighbouring stations are more dense than those underlying the other, $g-\gamma_C$ may be expected to be the greater over the first station; and, since H, the geoidal height, generally varies slowly with distance, $g-\gamma_D$ ($=g-\gamma_C - KH$) also may be expected to be greater. But this consideration by itself does not establish the likelihood of a correlation between $g-\gamma_D$ and the surface density in widely separated areas.

Table 6 gives (a) the vertical attraction of, and (b) the geoidal rise due to, an excess density of 10% in surface rocks of specified thickness covering a circular area of specified radius. The figures apply to the centre of the area. The greatest depth given (2 miles) is certainly the greatest at which geologists, unsupplied with geodetic data, would hazard a guess as to the comparative density of the crust at the same depth in different areas; and 10% excess or defect of density is a large, although perhaps not quite a maximum, abnormality for the average density of the surface rocks of any considerable area. It is noticeable that the attractions given are not very large, so that, except in the case of density anomalies of as much as 10°/₀, at least a mile thick, and covering a fairly limited area (under 100 miles diameter), the correlation can only be expected if $g-\gamma_D$ is remarkably free from all other sources of discrepancy. Now the average value of $g-\gamma_D$ (without regard to sign) is about ·020. Then, if $g-\gamma_D$ is to be correlated with the geology, i.e. if its values are to be attributed to the excessive or defective attraction of high or low density surface rocks, it must be concluded that a typical surface anomaly is one which will produce attractions of ·020 cm/sec^2. Table 6 shows that such an anomaly is a 10°/₀ excess density, 2 miles thick, covering an area *not more* than 100 miles in diameter. It is thought that geologists will hardly admit that such anomalies are typical; that in any area selected at random, the anomaly is as likely to be more striking as it is to be less. And whether such anomalies do exist or not, it is thought that no geologist will be able to produce, from the data of his own science, the evidence or even speculation necessary to establish the correlation.

A second reason for expecting no correlation is the fact mentioned by Major Glennie in para 14, namely that large areas of superficial excess will themselves cause a geoidal rise (an increase of H), which will result in diminution of $g-\gamma_D$. Table 6 shows that in the centre of an area 200 miles in diameter ·02H (i.e. KH) is about equal to the attraction, so that in such a case $g-\gamma_D$ should be zero, and in the centre of areas of greater extent the correlation with density should be negative. India is a country of large features, and it is not unusual for rocks of roughly similar density to be typical of areas as large as this.

The table given in para 14 hardly goes far enough to establish the correlation. In view of the difficulties outlined above, an empirical correlation will have to be remarkably strong, before it can be accepted as a fact.

In the above discussion it has been accepted as a standard, that excess superficial density is compensated in exactly the same way as topography of normal mass; it would be hard to argue in support of a system in which the compensation is appropriate to topography of true volume, but of exactly normal density, while any excess or defect of mass, which may be due to abnormal density, remains uncompensated. But if such a state should be considered reasonable, reference to Table 7 will show that it is no explanation of the difficulties met with on the more reasonable hypothesis, and that the correlation remains equally hard to explain.

TABLE 6.—*Attraction in cm/sec² (upper figure), and geoidal rise in feet (lower figure) at centre of disc of rock 10°/o overdense, of given radius and thickness, duly compensated.*

Radius \ Thickness	$\frac{1}{4}$ mile	$\frac{1}{2}$ mile	2 miles
5 miles	·004 0·1	·008 0·2	·027 0·7
25 miles	·003 0·3	·006 0·7	·025 2·7
100 miles	·001 0·6	·003 1·3	·012 5·2
400 miles	·000 0·8	·001 1·6	·003 6·5

For other density anomalies multiply in simple proportion.

TABLE 7.—*As Table 6, but without compensation.*

Radius \ Thickness	$\frac{1}{4}$ mile	$\frac{1}{2}$ mile	2 miles
5 miles	·004 0·1	·009 0·2	·030 0·9
25 miles	·005 0·6	·009 1·2	·035 5·
100 miles	·005 2·5	·009 5·	·037 20·
400 miles	·005 10·	·009 20·	·037 80·

26. Computation of Geoidal Rise.—In the computation of the isostatic geoid and of Tables 6 and 7, it has been necessary to calculate the geoidal rise at a given point, due to specified masses. The computation of the geoidal rise due to surrounding topography is a very easy computation, if only moderate accuracy is required, i.e. if an error of one or two feet can be tolerated.

Let the country be divided up into zones of radii r_2 (greater) and r_1, let the average height of any zone above sea-level be h, let the surface density be δ, and the Earth's mean density Δ, and let the Earth's mean radius be R. Let V be the potential of the uncompensated topography in any one zone, and let Y be the resulting geoidal rise.

$$\text{Then } V=2\pi\delta\left[\frac{h}{2}\sqrt{r^2+h^2}+\frac{r^2}{2}\log_e\frac{1}{r}\left(h+\sqrt{r^2+h^2}\right)-\frac{h^2}{2}\right]_{r_1}^{r_2}$$

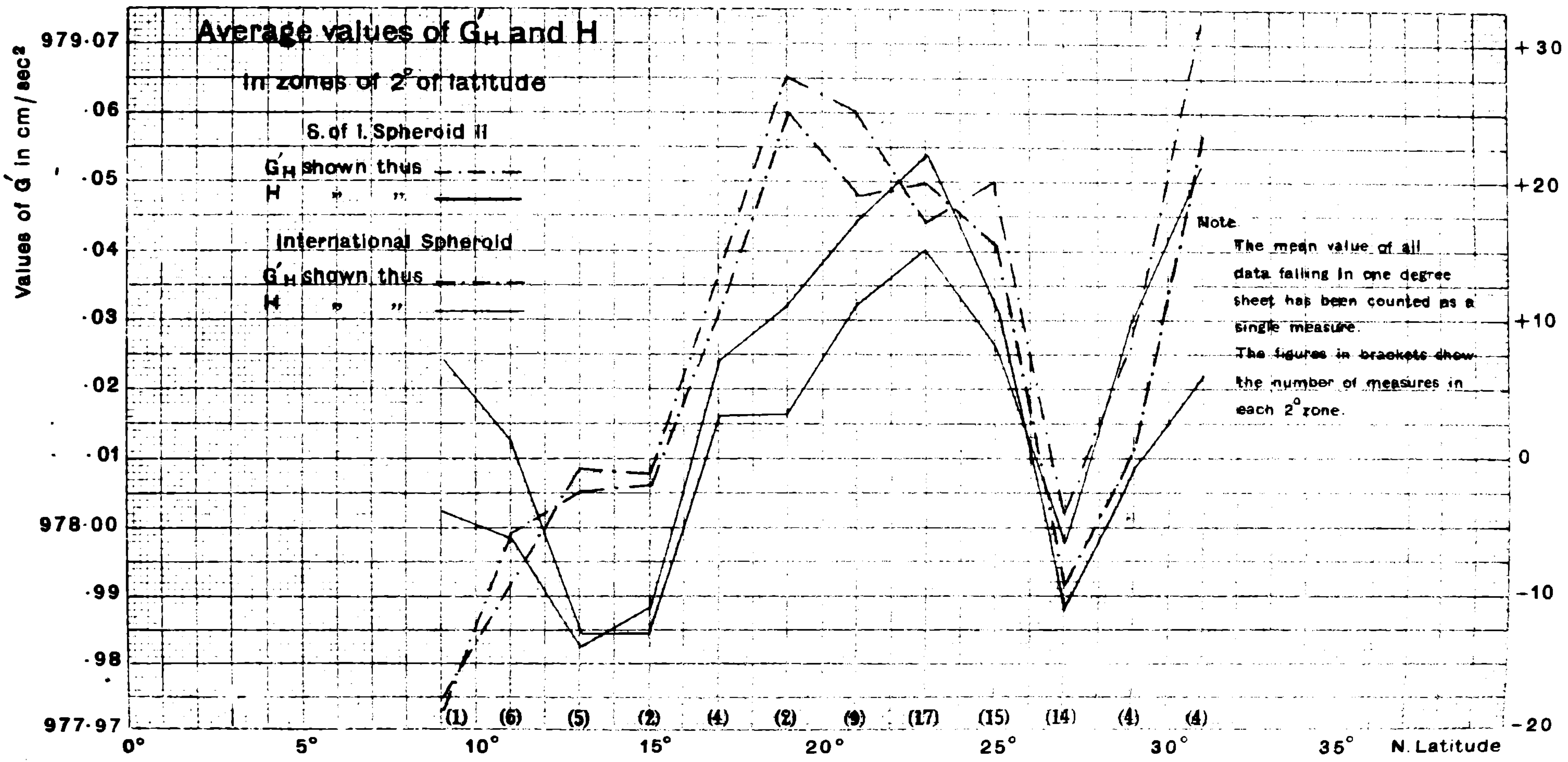
and $Y=3V/4\pi R\Delta$.

In the case of compensation, the "height" is always -70 miles, and the density is $h\delta/70$, the formulæ being the same. For compensated topography the rise is the rise due to the topography *minus* the rise due to the compensation.

Table 8 gives the geoidal rise due to compensated topography of different heights in zones of different radii. The zones are rather broad, and if the bulk of the mass in any one zone is situated near its inner border some inaccuracy will result. But a zone in which all the mass is concentrated near the inner border cannot be expected to have a great average height, and in any case a certain amount of cancelling of error is to be expected; it is thought that the use of these wide zones will not introduce errors of more than a couple of feet at most, except possibly in the innermost zone. This zone has deliberately been kept fairly large, for, when preparing such a figure as the isostatic geoid, it is desired to obtain the general geoidal level near each of the points selected for computation: it is not desired to obtain the abnormally high values which would result if the selected point happened to be near the top of a small peak.

As it stands, the table is not intended for the detailed computation of the geoidal rise between two near points such as Dehra Dūn and Mussoorie (see Chapter VII). It has been used for the construction of the charts showing the compensated and isostatic geoids, for which purpose the three inner zones have been combined, in order to give a suitably generalised result.

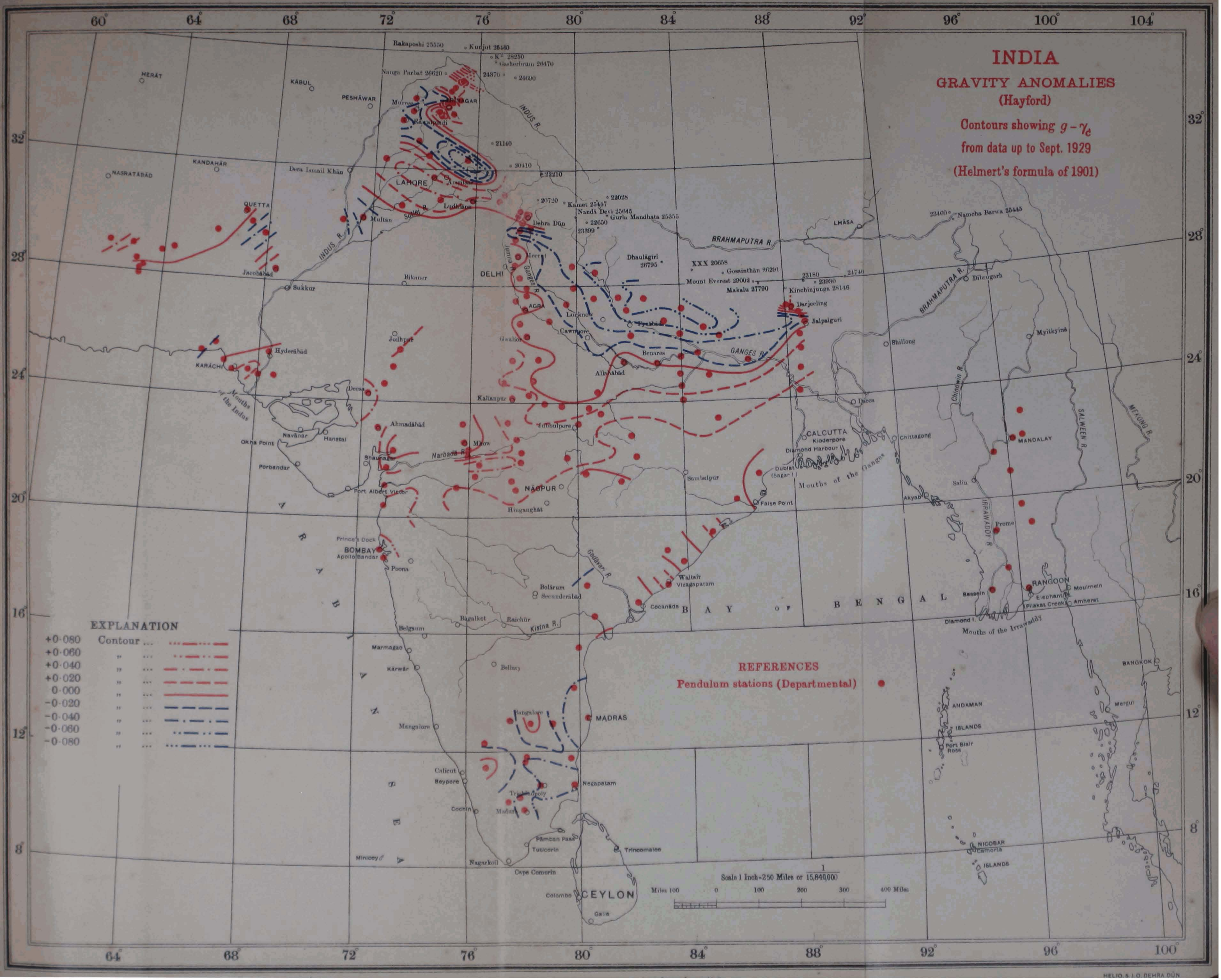
Chart VI



To accompany Geodetic Report Vol. V

REG. No. 1820 D.D.D.1930-500.

Chart VII



HELIO. & L.O. DEHRA DŪN

Chart VIII

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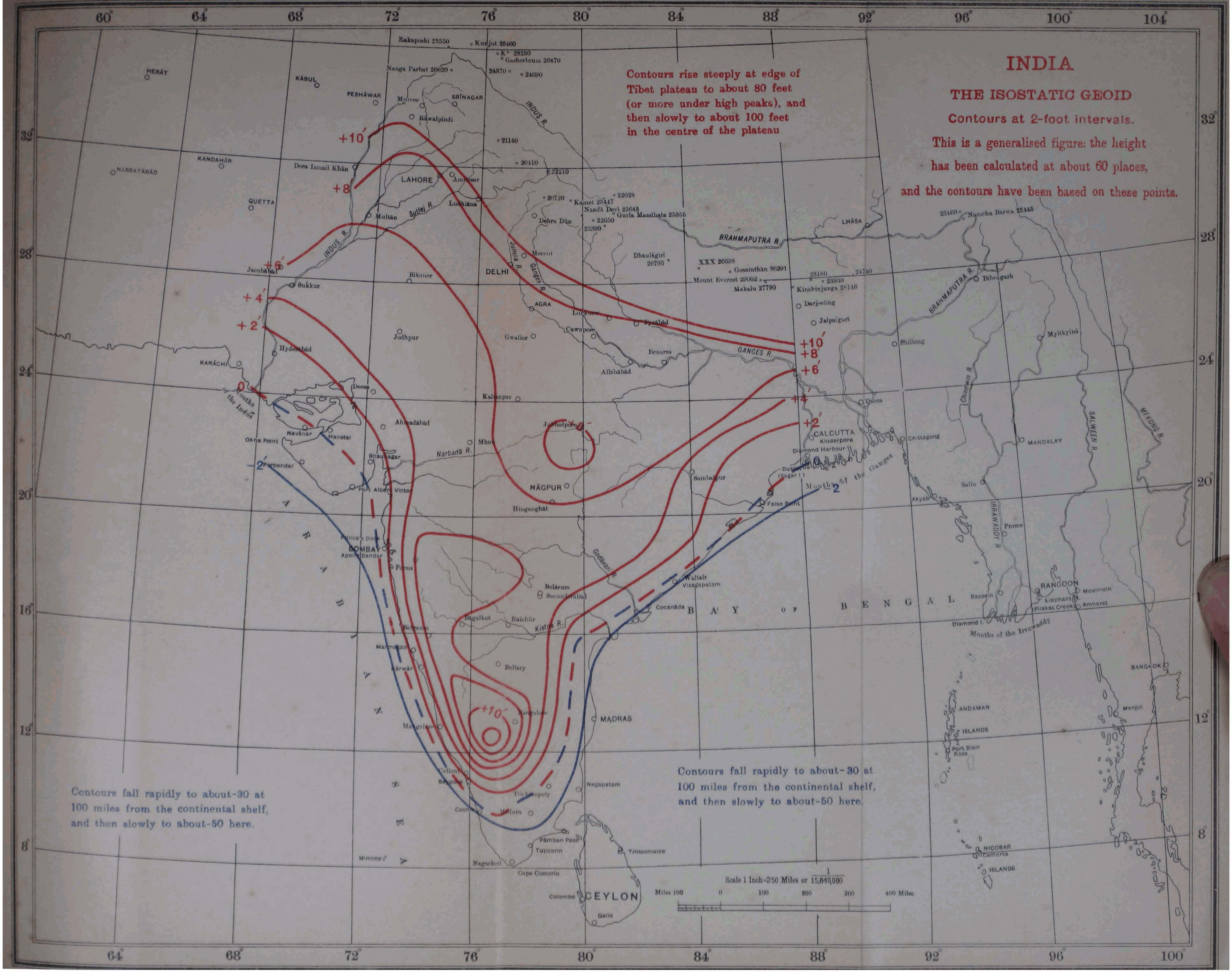
HELIO. S.I.O. DEHRA DŪN

Chart IX



INDIA
THE ISOSTATIC GEOID
Contours at 2-foot intervals.
This is a generalised figure: the height has been calculated at about 60 places, and the contours have been based on these points.
Contours rise steeply at edge of Tibet plateau to about 80 feet (or more under high peaks), and then slowly to about 100 feet in the centre of the plateau
Contours fall rapidly to about -30 at 100 miles from the continental shelf, and then slowly to about -50 here.
Contours fall rapidly to about -30 at 100 miles from the continental shelf, and then slowly to about -50 here.
+10′
+8
+6′
+4′
+2′
0
-2′
+10′
+8′
+6′
+4′
+2′
-2
+10′
ARABIAN SEA
BAY OF BENGAL
CEYLON
BOMBAY
MADRAS
CALCUTTA
DELHI
LAHORE
NĀGPUR
RANGOON
MANDALAY
LHĀSA
HERĀT
KĀBUL
PESHĀWAR
SRĪNAGAR
KANDAHĀR
QUETTA
KARĀCHI
ANDAMAN ISLANDS
NICOBAR ISLANDS
INDUS R.
BRAHMAPUTRA R.
GANGES R.
IRRAWADDY R.
SALWEEN R.
MEKONG R.
Mouths of the Ganges
Mouths of the Indus
Mouths of the Irrawaddy
Mount Everest 29002
Kinchinjunga 28146
Scale 1 Inch=250 Miles or 1/15,840,000
Miles 100 0 100 200 300 400 Miles

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

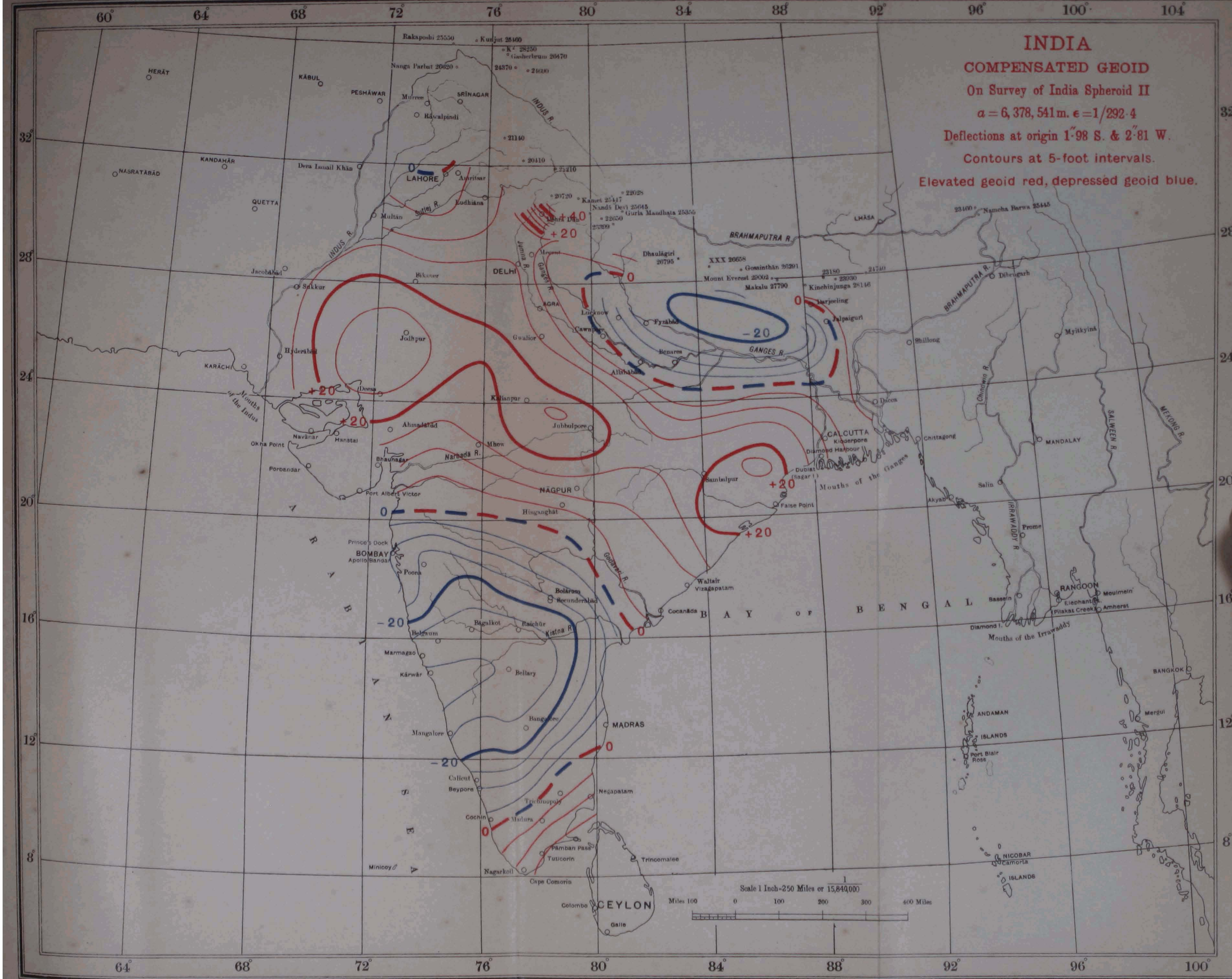

INDIA
COMPENSATED GEOID
On Survey of India Spheroid II
a = 6, 378, 541 m. ε = 1/292·4
Deflections at origin 1"·98 S. & 2"·81 W.
Contours at 5-foot intervals.
Elevated geoid red, depressed geoid blue.
ARABIAN SEA
BAY OF BENGAL
CEYLON
Mouths of the Indus
Mouths of the Ganges
Mouths of the Irrawaddy
INDUS R.
BRAHMAPUTRA R.
GANGES R.
Narbada R.
Godavari R.
Kistna R.
Jumna R.
Ganges R.
Sutlej R.
Chindwin R.
IRRAWADDY R.
SALWEEN R.
MEKONG R.
HERĀT
KĀBUL
PESHĀWAR
SRĪNAGAR
Murree
Rāwalpindi
KANDAHĀR
NASRATĀBĀD
QUETTA
Dera Ismail Khān
LAHORE
Amritsar
Ludhiāna
Multān
Jacobābād
Sukkur
Bīkaner
DELHI
Meerut
AGRA
Gwalior
Jodhpur
Hyderābād
KARĀCHI
Deesa
Ahmadābād
Okha Point
Navānar
Hanstal
Porbandar
Bhaunagar
Port Albert Victor
Mhow
Jubbulpore
Lucknow
Cawnpore
Fyzābād
Benares
Allahābād
NĀGPUR
Hinganghāt
Prince's Dock
BOMBAY
Apollo Bandar
Poona
Bolārum
Secunderābād
Waltair
Vizagapatam
Cocanāda
Belgaum
Bagalkot
Raichūr
Marmagao
Kārwār
Bellary
Bangalore
Mangalore
MADRAS
Calicut
Beypore
Cochin
Madura
Trichinopoly
Negapatam
Pāmban Pass
Tuticorin
Nagarkoil
Cape Comorin
Trincomalee
Colombo
Galle
Minicoy
CALCUTTA
Kidderpore
Diamond Harbour
Dublat (Sagar I.)
Santalpur
False Point
Dacca
Chittagong
Darjeeling
Jalpaiguri
Shillong
Dibrugarh
Myitkyinā
MANDALAY
Sālin
Akyab
Prome
Bassein
RANGOON
Elephant Pt.
Pilakas Creek
Moulmein
Amherst
Diamond I.
BANGKOK
Mergui
ANDAMAN ISLANDS
Port Blair
Ross
NICOBAR ISLANDS
Camorta
LHĀSA
Rakaposhi 25550
Nanga Parbat 26620
K² 28250
Gasherbrum 26470
Kamet 25447
Nandā Devi 25645
Gurla Mandhata 25355
Dhaulāgiri 26795
XXX 26658
Gosainthān 26291
Mount Everest 29002
Makalu 27790
Kinchinjunga 28146
Namcha Barwa 25445
Scale 1 Inch = 250 Miles or 1/15,840,000
Miles 100 0 100 200 300 400 Miles
+20
+40
0
−20

Chart XII

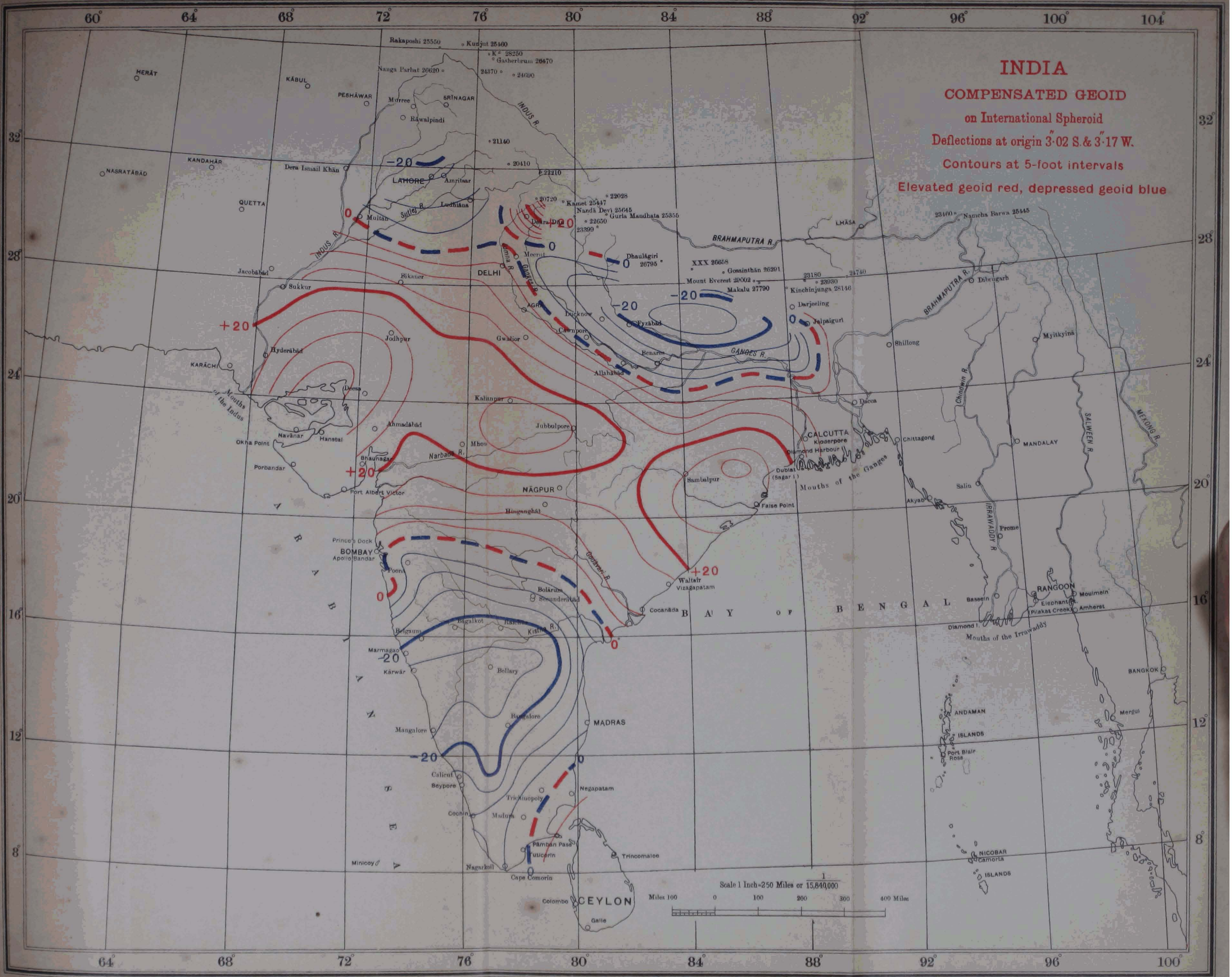
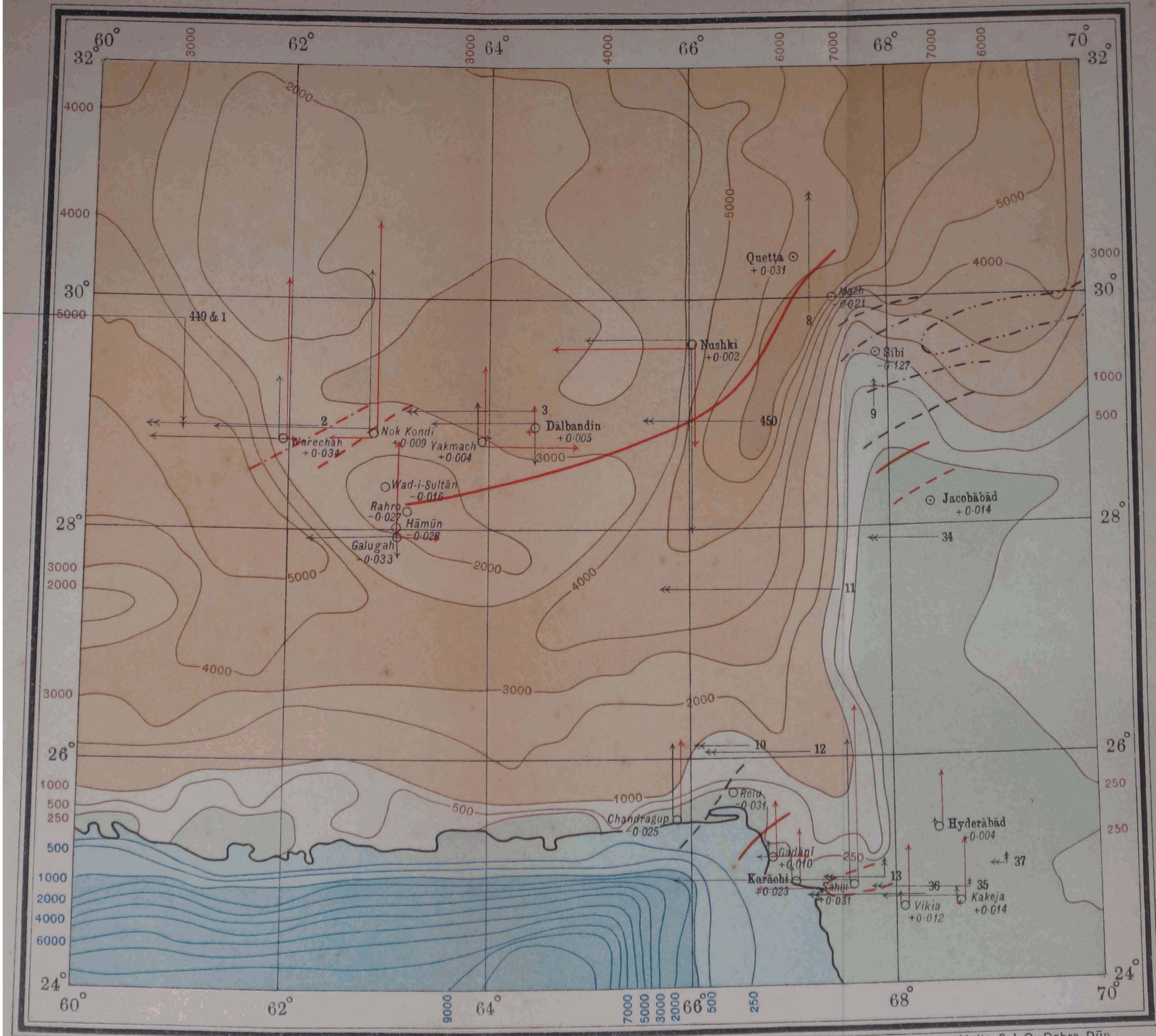

INDIA
COMPENSATED GEOID
on International Spheroid
Deflections at origin 3″·02 S. & 3″·17 W.
Contours at 5-foot intervals
Elevated geoid red, depressed geoid blue
HERĀT
KĀBUL
PESHĀWAR
Murree
SRĪNAGAR
Rāwalpindi
KANDAHĀR
NASRATĀBĀD
QUETTA
Dera Ismail Khān
LAHORE
Amritsar
Ludhiāna
Multān
Sutlej R.
INDUS R.
Jacobābād
Sukkur
Bikaner
DELHI
Meerut
AGRA
Jodhpur
Gwalior
Hyderābād
KARĀCHI
Deesa
Mouths of the Indus
Ahmadābād
Navānar
Hanstal
Okha Point
Porbandar
Bhaunagar
Port Albert Victor
Kalianpur
Jubbulpore
Mhow
Narbada R.
NĀGPUR
Hinganghāt
Lucknow
Cawnpore
Fyzābād
Benares
Allahābād
GANGES R.
Dhaulāgiri 26795
Mount Everest 29002
Makalu 27790
Gosainthān 26291
Kinchinjunga 28146
Darjeeling
Jalpaiguri
LHĀSA
BRAHMAPUTRA R.
Namcha Barwa 25445
Dibrugarh
Shillong
Myitkyina
Dacca
CALCUTTA
Kidderpore
Diamond Harbour
Dublat (Sagar I.)
Mouths of the Ganges
Chittagong
MANDALAY
Samlalpur
False Point
Akyab
Salin
Prome
IRRAWADDY R.
SALWEEN R.
MEKONG R.
Chindwin R.
Rakaposhi 25550
Kunjut 25460
K² 28250
Gasherbrum 26470
Nanga Parbat 26620
Kamet 25447
Nandā Devi 25645
Gurla Mandhata 25355
Prince's Dock
BOMBAY
Apollo Bandar
Poona
Bolārum
Secunderābād
Godāvari R.
Kistna R.
Waltair
Vizagapatam
Cocanāda
BAY OF BENGAL
ARABIAN SEA
Bassein
RANGOON
Moulmein
Elephant
Pilakat Creek
Amherst
Diamond I.
Mouths of the Irrawaddy
Belgaum
Bagalkot
Raichur
Marmagao
Kārwār
Bellary
Bangalore
Mangalore
MADRAS
Calicut
Beypore
Cochin
Madura
Trichinopoly
Negapatam
Pāmban Pass
Tuticorin
Nagarkoil
Cape Comorin
Minicoy
Trincomalee
CEYLON
Colombo
Galle
ANDAMAN ISLANDS
Port Blair
Ross
NICOBAR ISLANDS
Camorta
BANGKOK
Mergui
Scale 1 Inch = 250 Miles or 1/15,840,000
Miles 100 0 100 200 300 400 Miles

CHART OF OBSERVATIONS FOR GRAVITY IN BALUCHISTĀN AND SIND

Chart XIII



Reg. No. 30 D.D.D. 1930 (C.O.)-S. I.-500.

Helio. S. I. O. Dehra Dūn

REFERENCES

Gravity Stations season 1927-28 .... ○

,, ,, previous seasons .... ⊙

Free air Gravity anomalies ...... +0·005 Cm/Sec^2

Deflections: Everest's Spheroid: 1927-28 ——→

,, ,, ,, Old ——→→

Hayford anomalies: International Spheroid ——→

Scale $\frac{1}{5,000,000}$ or 1·014 Inches to 80 Miles

Miles 50 25 0 50 100 Miles

Note:- Height Contours are in feet and show average heights or depths.

Deflection Scale 1 Cm=5″

Hayford gravity anomaly contours

-·060 Cm/Sec^2

-·040

-·020

+·000

+·020

+·040

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HELIO S.I.O. DEHRA DUN

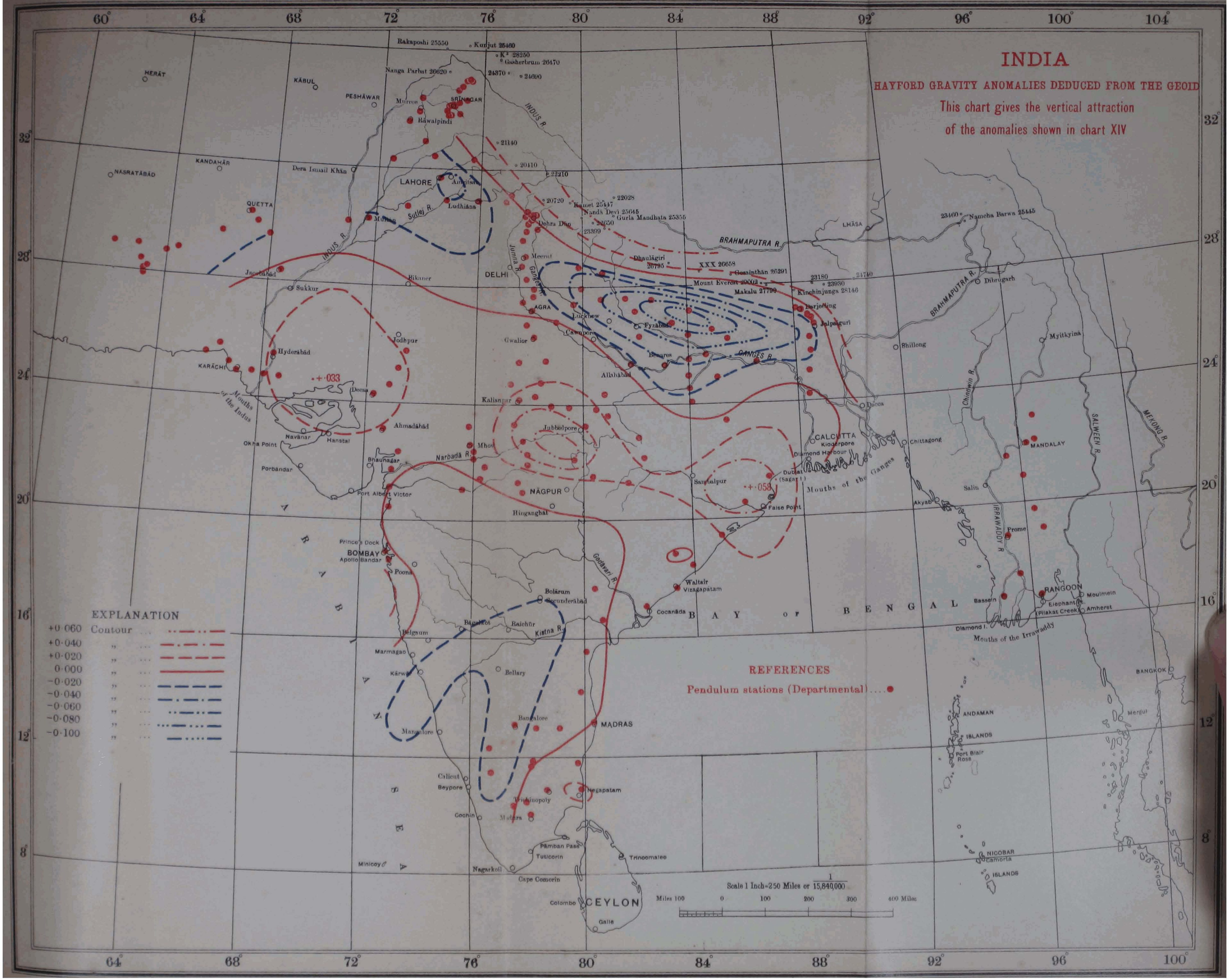

INDIA
HAYFORD GRAVITY ANOMALIES DEDUCED FROM THE GEOID
This chart gives the vertical attraction
of the anomalies shown in chart XIV
EXPLANATION
+0·060 Contour
+0·040 "
+0·020 "
0·000 "
−0·020 "
−0·040 "
−0·060 "
−0·080 "
−0·100 "
REFERENCES
Pendulum stations (Departmental)
Scale 1 Inch=250 Miles or 1/15,840,000
Miles 100 0 100 200 300 400 Miles
BAY OF BENGAL
ARABIAN SEA
CEYLON
ANDAMAN ISLANDS
NICOBAR ISLANDS
BOMBAY
MADRAS
CALCUTTA
DELHI
LAHORE
KARĀCHI
NĀGPUR
RANGOON
MANDALAY
+·033
+·058

TABLE 8.—*Geoidal Rise (in feet) due to compensated topography.*

Radius of Zone in miles	Average height of zone in feet											
	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000
A 0 to 10	1·3	2·6	3·8	5·2	6·5	7·8	8·9	10·2	11·4	12·5	13·7	14·9
B 10 to 25	1·4	2·8	4·1	5·4	6·6	7·8	9·2	10·6	11·9	13·4	14·7	16·1
C 25 to 50	1·3	2·5	3·6	4·7	5·9	7·1	8·3	9·7	11·0	12·3	13·7	15·0
D 50 to 100	1·2	2·3	3·3	4·2	5·3	6·3	7·1	8·1	8·6	9·2	10·0	10·8
E 100 to 400	1·3	2·6	3·5	4·4	5·3	6·2	7·1	8·0	9·3	10·6	11·8	13·1

The depth of sea zones should be multiplied by ·615; the rise is of course negative.

Chapter V

TRIANGULATION

BY CAPTAIN G. BOMFORD, R.E.

1. **Summary.**—The season's programme consisted of primary triangulation in Burma with two detachments, both using Wild Precision (5½″) theodolites. This was the first occasion on which the Wild type of theodolite has been used for primary triangulation by the Survey of India.

No. 1 Detachment, under Mr. B.L. Gulatee undertook the observation of the Chittagong series, a longitudinal series about 125 miles long, connecting the Burma Coast and Manipur Meridional series in latitude 22½°E. The series was completed except for a few observations near Chittagong which had to be left until next year. The accuracy of observation was satisfactory, the mean triangular error being 0″·59, and the value of m (the mean square error of an angle) being 0″·41.

No. 2 Detachment, under Mr. P.K. Ghosh undertook the reobservation of part of the Mong Hsat secondary series, and made a connection with the triangulators of the Siamese Survey in Lat. 20°N. Long. 99°E. The Mong Hsat series runs westwards from this junction to the Mandalay Meridional series in Long. 97°E., a distance of 170 miles. About half the observations were completed, but a defect in the theodolite, combined with the inexperience of the observer, resulted in the observations being faulty, and the work will have to be repeated next year.

From the beginning of the season until the end of December no officer was available to take active charge of the party, which was consequently administered at different times by the officers in charge of the Pendulum and Computing Parties. Captain Bomford was then in charge until the end of April. During recess Lieut. Cadell and Mr. N.R. Mazumdar held charge at different times. These frequent changes, although unavoidable, were detrimental to the efficiency of the party, and the lack of a full time officer in charge at the beginning of the season, when the observing personnel was untrained in geodetic triangulation, must be considered a contributary cause of the failure of No. 2 Detachment.

The Wild Precision theodolites, on which a fuller report is given later (para 5), both exhibited serious defects, but give great

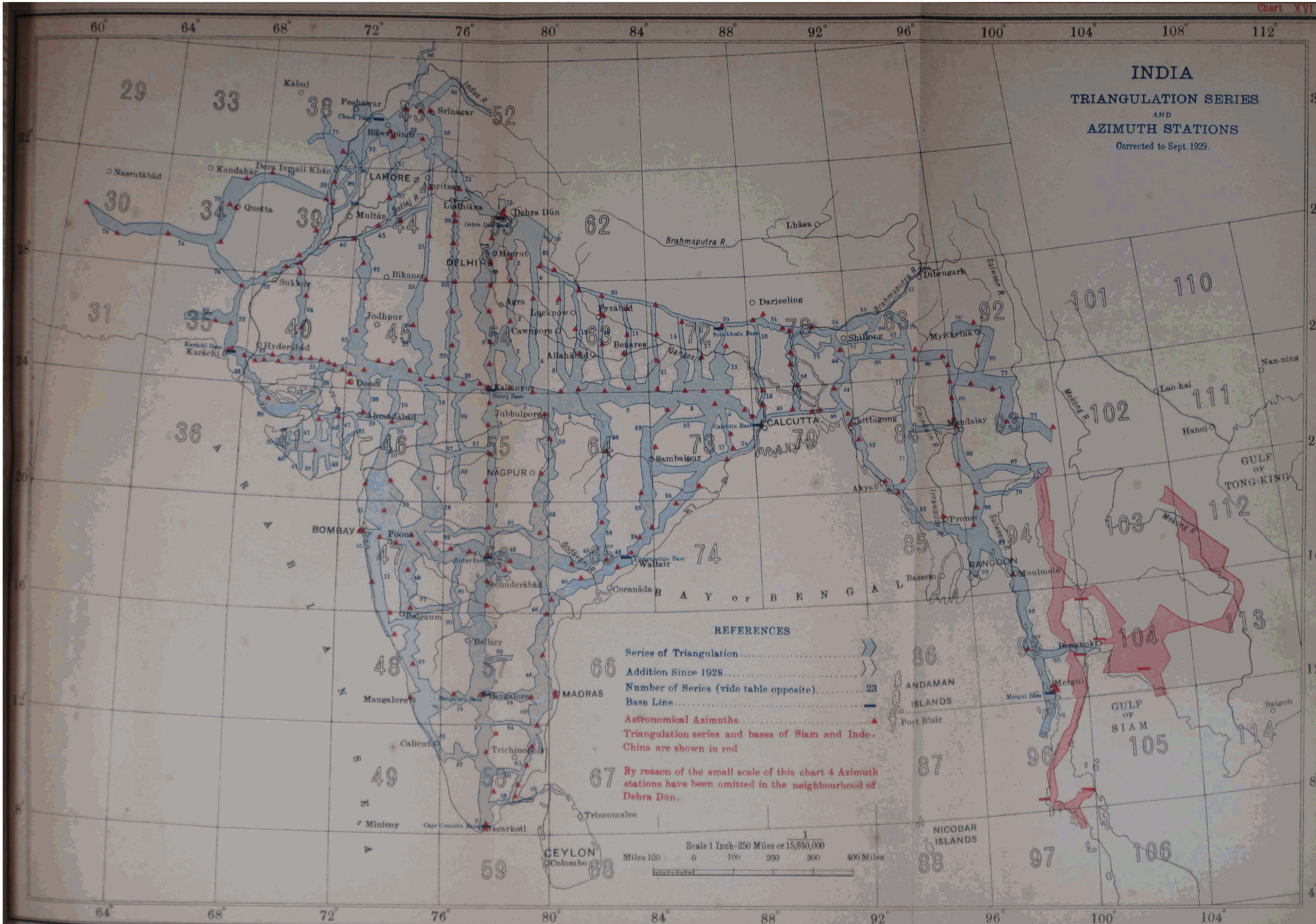
Reference numbers and Values of "*m*" and "M" for all Geodetic Series of the Indian Triangulation. (*See* Records of the Survey of India Vol. IX, p. 137).

For 42 Series entering the Simultaneous Grinding (shown in italics below) Mean Square M = ± 1·04
For Series up to No. 99 ... ... Mean Square M = ± 1·53

No.	Name of Series	Seasons	± *m*	± M
1	South Pārasnāth Mer. ...	1831-39	3·308	3·26
2	Budhon Meridional ...	1833-43	2·242	2·46
3	*Amūa Meridional* ...	1831-38	1·647	1·88
4	*Rangīr Meridional* ...	1834-64	1·643	1·79
5	*Calcutta Longitudinal* ...	1834-69	0·369	0·32
6	*Great Arc Meridional, Section 24°-30°* ...	1835-66	0·708	0·71
7	*Bombay Longitudinal* ...	1837-63	0·844	0·74
8	*Great Arc Meridional, Section 18°-24°* ...	1838-41	0·567	0·59
9	*Great Arc Meridional, Section 8°-18°* ...	1840-74	0·390	0·36
10	*Singi Meridional* ...	1842-62	1·187	1·14
11	*South Konkan Coast* ...	1842-67	2·176	1·93
12	*Karāra Meridional* ...	1843-45	1·507	1·81
13	*North Malūncha Mer.* ...	1844-46	1·266	1·42
14	*Chendwār Meridional* ...	1844-69	0·841	1·06
15	*Gora Meridional* ...	1845-47	0·973	1·21
16	*Calcutta Meridional* ...	1845-48	1·173	1·99
17	South Malūncha Mer. ...	1845-53	1·606	1·97
18	*Khānpisura Meridional* ...	1845-62	1·227	1·07
19	*Gurwāni Meridional* ...	1846-47	1·165	1·55
20	*North-East Lon.* ...	1846-55	0·446	0·65
21	*Hurilāong Meridional* ...	1848-52	1·502	1·92
22	*North-West Himālaya* ...	1848-53	0·641	0·55
23	*Gurhāgarh Meridional* ...	1848-62	0·914	1·21
24	*East Coast* ...	1848-63	0·608	0·70
25	*Karāchi Longitudinal* ...	1849-53	0·558	0·60
26	*Abu Meridional* ...	1851-52	0·617	0·68
27	*North Pārasnāth Mer.* ...	1851-52	0·895	1·25
28	*Kāthiāwār Meridional* ...	1852-56	0·990	1·11
29	*Gujarāt Longitudinal* ...	1852-62	0·859	1·12
30	Kāthiāwār Lon. ...	1853	1·481	1·34
31	Sābarmati ...	1853-54	1·348	2·84
32	*Great Indus* ...	1853-61	0·359	0·43
33	*Rāhon Meridional* ...	1853-63	0·327	0·37
34	*Assam Longitudinal* ...	1854-60	0·579	0·71
35	*Cutch Coast* ...	1855-58	0·986	1·27
36	Kashmīr Principal ...	1855-60	0·884	0·86
37	*Jogi-Tila Meridional* ...	1855-63	0·481	0·59
38	Sambalpur Lon. ...	1856-57	0·806	0·87
39	(Cutch) Coast Line ...	1856-60	0·975	1·47
40	Kāthiāwār Meridional No. 1 ...	1858-59	0·930	1·51
41	Kāthiāwār Meridional No. 2 ...	1859-60	1·247	1·75
42	Kāthiāwār Meridional No. 3 ...	1859-60	0·969	1·48
43	*Bīdar Longitudinal* ...	1859-72	0·311	0·30
44	*Eastern Frontier or Shillong Meridional* ...	1860-64	0·409	0·49
45	*Sutlej* ...	1861-63	0·346	0·53
46	*Madras Mer. and Coast* ...	1861-68	0·426	0·40
47	Kāthiāwār Meridional No. 4 ...	1863-64	1·154	1·73
48	*East Calcutta Lon.* ...	1863-69	0·379	0·57
49	*Mangalore Meridional* ...	1863-73	0·440	0·45
50	Kumaun and Garhwāl ...	1864-65	1·742	1·50
51	Nāsik ...	1864-65	2·033	3·12
52	Burma Coast ...	1864-82	0·380	0·99
53	*Jubbulpore Meridional* ...	1865-67	0·340	0·31
54	*Madras Longitudinal* ...	1865-80	0·384	0·37
55	Assam Valley Triangulation ...	1867-78	1·690	2·65
56	*Brahmaputra Mer.* ...	1868-74	0·564	0·70
57	Coimbatore No. 1 ...	1869-71	1·547	2·07
58	*Bilāspur Meridional* ...	1869-73	0·302	0·33
59	Cuddapah ...	1871-72	0·826	0·96
60	Hyderābād ...	1871-72	1·405	1·56
61	Malabar Coast ...	1871,74.80	1·532	1·82
62	Jodhpur Meridional ...	1873-76	0·291	0·32
63	*South East Coast* ...	1875-79	0·522	0·65
64	Eastern Sind Mer. ...	1876-81	0·244	0·30
65	Siam Branch Triangulation ...	1878-81	3·711	4·34
66	Mandalay Meridional ...	1889-95	0·418	0·35
67	Mong Heat ...	1891-93	3·054	3·01
68	Manipur Longitudinal ...	1894-99	0·453	0·36
69	Makrān Longitudinal ...	1895-97	0·285	0·26
70	Mandalay Lon. ...	1899-1909	1·696	1·96
71	Manipur Mer. ...	1899-1902 } 1915-1916 }	0·750	0·81
72	Great Salween ...	1900-11	0·404	0·32
73	Kidarkanta ...	1902-03	1·323	1·62
74	Kalāt Longitudinal ...	1904-08	0·365	0·25
75	Baluchistān Triangulation ...	1908-09	1·348	1·08
76	North Baluchistān ...	1908-10	0·221	0·17
77	Gilgit ...	1909-11	0·143	0·37
78	Khāsi Hills ...	1909-11	2·038	3·01
79	Mawkmai ...	1909-11	1·575	2·35
80	Upper Irrawaddy ...	1909-11	0·596	0·49
81	Jaintiā Hills ...	1910-11	0·986	1·86
82	Bhīr ...	1911-12	0·794	0·94
83	Rānchi ...	1911-12	1·840	2·34
84	Villupuram ...	1911-12	1·184	1·78
85	Sambalpur Meridional ...	1911-14	0·250	0·21
86	Indo-Russian Connection	1912-13	2·790	3·92
87	Khandwā ...	1912-13	0·999	1·27
88	Ashta ...	1913-15	1·048	1·33
89	Buldāna ...	1913-14	0·304	0·43
90	Naldrug ...	1913-14	1·465	1·85
91	Nāga Hills ...	1913-14	0·913	0·96
92	Middle Godāvari ...	1914-15	0·913	1·08
93	Kohimā ...	1914-15	1·094	1·39
94	Cāchār ...	1914-15	1·077	1·65
95	Bombay Island ...	1911-14		
96	Madura ...	1916-17	1·148	1·53
97	Bāgalkot ...	1916-17	0·701	0·83
98	Sind Sāgar Triangulation	1917-18	1·875	3·24
99	Rangoon ...	1925-27	1·246	1·25

Mer. = Meridional. Lon. = Longitudinal.

Chart XVI



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promise for the future. It is expected that in future they will combine an accuracy at least equal to that of the 12-inch theodolites with their many undoubted advantages over the older type of instrument.

The season's work brought to light the necessity for a revision of that part of the handbook which deals with geodetic triangulation. The preparation of a new handbook has been taken in hand, and about half has been completed.

A small detachment under B. Mukhtar Ahmed, administered by O. C. 14 Party (Pendulum) was employed on the locating and repairing of the East Coast series from Balasore towards the south. The sea has encroached in places, and many new villages have sprung up, with the result that out of 49 stations visited, only 20 could be definitely located and repaired.

2. Chittagong Series.—The stations of this series are shown in Chart XVII. Except for the connection with the Manipur Meridional series at the east end, the reconnaissance was made and the stations built as long ago as 1914-15, but the long break in geodetic work which resulted from the war, caused the observations to be postponed until 14 years later. In the middle of the series the figures are considerably weaker than has been usual for primary triangulation in India, but the country is difficult, and a less narrow series would have added considerably to the difficulties of observation.

Work was started at the west end of the series at the beginning of October. As reconnoitred, the series connected with the Burma Coast series at Mora Tān, Kurla and Sitapahār hill stations, but after clearing these and some forward stations, and after observing at Kurla and Mora Tān, it was discovered that the stations at Foromoin and Sitapahār were not intervisible. To have recommenced the series from a fresh base at this stage would have involved considerable delay and disorganisation of all arrangements. In view of the fact that it was possible to compute the series without the missing angles, although not by the orthodox method, Mr. Gulatee decided to keep to his original plan, without visiting any additional stations. It was afterwards decided that the connection must be strengthened by further observations at Sitapahār, Gilachhari, Phukamoin and Mullianphui, but it was not possible to complete them during the season.

From this point work proceeded rapidly as far as the stations Lungleng and Blue Mountain, excellent triangular errors being obtained, but the theodolite then began to show some signs of stiffness in its vertical axis. Observations at these two stations were completed, but after the march forward to Haka the axis was found to be unworkably stiff. No provision is made for oiling the axis of the Wild theodolite, and efforts to introduce oil were not successful. The construction of the Wild is not such that the instrument can lightly be dismantled in the field, and it was accordingly taken to Calcutta for repair at the Mathematical Instrument Office. It was there taken down with some difficulty, and the fault was corrected. But a month had been wasted.

Before taking the theodolite to Calcutta Mr. Gulatee had completed the reconnaissance of the east end of the series, and had built a new station at Mongklang. When observations were recommenced at Zemuklang on February 23rd on his return from Calcutta, the visibility, which had previously been good, had become considerably worse by reason of the haze which is always found in Burma at that time. On account of the haze the observations could only be completed with great difficulty, and the work closed on the base Waibula—Wone-lone-taung on March 17th. At this time of the year it was quite out of the question to return to Chittagong and complete the connection with the Burma Coast series, and the detachment returned to India via the Chindwin river and Rangoon.

In addition to the loss of a month's work, the stiffness of the theodolite's axis at Lungleng and Blue Mountain, combined with the bad visibility at Zemuklang and Zovailangklang caused rather exceptionally large triangular errors in the quadrilateral formed by these four stations. The closures there averaged $1''\cdot03$, as compared with $0''\cdot47$ in the rest of the series.

Observations were made generally by day, sometimes by night, the former to 9-inch helios, and the latter to oil lamps. Until February the visibility was generally good in the morning and after 4 p.m., but between 10 a.m. and 4 p.m. the higher hill tops were usually obscured by mist rising from the valleys; thus, although there was no difficulty in observing horizontal angles, the vertical angles could not always be observed during the hours of minimum refraction.

The strength of the detachment was one observer, one assistant (Upper Subordinate Service), one recorder and 50 khalāsis. Health was poor. In the Chittagong Hill Tracts much sickness was caused by fever, and in the higher hills the khalāsis suffered from the cold. One khalāsi died of pneumonia in the Lushai Hills.

The country passed through is not easy for triangulation. Except on the Karnaphuli river and the Falam-Kalemyo road, only cooly transport can be used, and coolies are not easily obtained. From Chittagong to Demāgiri, the Karnaphuli river constitutes a central line of communication, but hills far from the river are only reached with difficulty. From Demāgiri there is only a cooly track through Lungleh to Haka in the Chin Hills, and supplies in the Lushai Hills can only be obtained from Lungleh. In the west the low hills are covered with dense bamboo jungle. The higher hills in the east are less thickly covered, but except Yetagong and Waibula they are not easy of access.

3. Mong Hsat Series.—This series had been observed with poor secondary accuracy in 1891-93. In recent years the extension of primary triangulation by the Siamese Survey has led to the possibility of a connection with the Indian triangulation at the east end of the Mong Hsat series. The 1928-29 programme was to make the connection with the Siamese triangulators, and to reobserve as much as possible of the old series.

Some of the figures of the old secondary series were very weak. Changes were made in the position of a few of the stations, which improved the lay-out a little, but some figures remained much weaker than is usual. As in the case of the Chittagong series, the difficulty of communication (at the east end) is such that any considerable improvement can only be obtained at the expense of much delay. It may be remarked, however, that these weak figures need not result in any weakness in the triangulation as a whole, provided they are associated with a closer base control than is usual. The provision of additional bases in Burma is now under consideration.

The detachment left Dehra Dūn on 19th September, and met the Siamese observers on the far side of the frontier on 3rd November, where it was arranged to make the connection by both parties' observing all three angles of the triangle Loi Pahompok, Loi Pakulin, Loi Tum.

At Loi Pakulin, the second station, the vertical axis of the Wild theodolite, which had always been too stiff, became so stiff as to be unusable. To have taken it to Calcutta, or to have waited for a new theodolite, would have resulted in the loss of nearly the whole season's work, and Mr. Ghosh accordingly took down the theodolite and oiled the axis. He reassembled the instrument successfully, and it then returned to its former condition of stiffness, namely workable but, as it turned out, too stiff for accurate work.

The observations then proceeded rather slowly, being hampered by cloudy weather. At Loi Salu the theodolite again became impossibly stiff and had to be dismantled. After the end of January the usual Burma haze caused difficulty, but the short sides between Loi Nan, Loi Lom and Loi Kaha enabled work to be continued as far as the side Loi Lom—Loi Kaha, where the detachment ceased work on February 23rd.

Observations were made partly by day and partly by night, the majority being by day, as in the Chittagong series. Cloudy weather caused some difficulty with helios, and delay was also caused by mist and haze.

The health of the detachment was poor, especially in the early part of the season when there was much malaria. One khalāsi died.

Communications to the east of Loi Salu consist of hill tracks, generally passable for ponies. The hills are steep and the river valleys deeply cut, but it was found possible to get pony transport up to most of the stations. West of Möngnai the country consists of very pleasant rolling downs with some rocky ridges, and a number of fair weather motor tracks.

4. Computations.—In view of the large triangular errors of the Mong Hsat series (average over 4″), only the Chittagong series was computed. The computations were begun from the east end, and carried up to the side Barkal-Mullianphui, beyond which they will be affected by the observations to be made next year. The computations followed the usual procedure, except that some saving was made in the computation of the weights of the angles, and some irregularity in the computation of heights was necessitated by the fact of their sometimes having been observed early in the day.

The system by which weights have previously been computed involves a full page of computation on form 7 Trian. for each angle. In view of the fact that unknown systematic errors probably have at least as serious an effect on the result of an angle, as do the casual errors of graduation and observation, so much labour is not justified. A shorter method was therefore adopted as follows. Let v_1, v_2, etc., be the differences between the general mean value of the angle, and the mean of the measures on each of n zeros, then the probable error of the general mean is $\frac{\cdot 845\ \Sigma|v|}{n\sqrt{n-1}}$, and the weight is given by $w = \frac{1}{(p.e.)^2} = \frac{1 \cdot 40\ n^2(n-1)}{(\Sigma|v|)^2}$ where $\Sigma|v|$ indicates the sum of v_1, v_2, etc., without regard to sign.

Some details of the height computations are given in the appendix to this chapter.

5. Wild Precision Theodolites.—The experience of the Survey of India with the Wild Precision theodolite has not been fortunate. The speed of work, and ease of transport is fully appreciated, but in their first season (1928-29) instrumental defects have resulted in considerable loss. These defects are summarized below:—

No. 59–(1) The vertical axis stiffened after observations at nine stations. It recovered after oiling.

(2) Towards the end of the season the horizontal axis showed some stiffness.

(3) Movement of the vertical slow motion screw causes a difference of several seconds in the horizontal pointing, according to the direction in which the screw is last turned. This defect was not noticed at first, and may not have developed until after the theodolite was first dismantled.

(4) The illumination of the cross wires is inadequate. Illumination has always had to be provided by torch through the object glass.

(5) The images of the two opposite sides of the horizontal circle are not now brought to a focus in a common plane. The error is small and there is no serious parallax, but some observers are troubled by the impossibility of getting both images in perfect focus. This defect also probably developed after the theodolite had been dismantled in India.

No. 37–(6) The vertical axis is permanently stiff; too stiff for accurate work. Every few months it has become so stiff that the theodolite can hardly be turned on its axis. Oiling has returned it to its previous condition.

(7) The illumination of the wires is defective as in No. 59.

If such defects as these had occurred in an ordinary theodolite, none except the stiffness of No. 37, would have caused any trouble. They could have been remedied in an hour or two. The Wild factory is of course capable of putting them right, but without very clear instructions it is quite beyond the power of the triangulator to do so in the field. The vertical axis can easily be oiled in the field, once the method is known, but the other adjustments have caused difficulty even to the well equipped Mathematical Instrument Office in Calcutta.

The conclusion to be drawn from the above, is that if Wild Precision theodolites are to be relied on for work in outlying countries, the makers must supply a detailed book of instructions, and, if necessary, a set of special tools, by means of which a man of the type usually employed on primary triangulation can get at and dismantle any part of his theodolite. He must be told where to start and what to leave untouched, which screws are left-handed, which joints are pinned, and which are friction grips; where force may be used, and where he must be careful. It cannot be said that Wild theodolites can be trusted to maintain the state of perfect adjustment, in which their makers may issue them.

Turning to more favourable aspects, it is unnecessary to say anything of the Wild's convenience in use: anyone who has used a Wild is likely to be repelled by the sight of a 12-inch theodolite of the old type. As regards accuracy, No. 37 has provided no data from which it can be judged, but No. 59 has given results which show that a Wild Precision theodolite in good order is capable of good primary triangulation, and which give grounds for hoping that it will be able to equal or even to surpass the best 12-inch theodolites.

In the Chittagong series the programme was to observe three measures face right, and three face left, on each of twelve zeros. By an oversight, the zeros selected were 0°, 30°, 60° etc., so that the programme was equivalent to twelve measures on each of six zeros. Each intersection and reading of the arc was repeated twice. Except in one quadrilateral which was affected by the stiffness of the axis, the average triangular error in 16 triangles was 0″·47. For the whole series of 20 triangles this figure was 0″·59, and the mean square error of an unadjusted angle was 0″·41. This is not as good as the best 12-inch theodolite work in which the mean square error may be 0″·3 or even 0·2, but it may be noted that it was the observer's first season of observation, and that further experience of the Wild may lead to improvements in a programme of work which was designed for the 12-inch theodolites.

The graduation of the horizontal circle of No. 59 appears to be excellent. All the measures made on different zeros have been classified according to the part of the circle on which they were measured, and the values of each zero mean *minus* the general mean value of the angle have been recorded. Table 1 gives the resulting mean value of Z.M. – G.M. for angles measured in different parts of the arc. Thus the figure +0·89 in the 13th column of the first row, signifies that all the measures of all angles whose one arm was between 300° and 310° or 120° and 130°, and whose other arm was between 360° and 10° or 180° and 190°, averaged 0″·89 greater than the general mean of all the measures of the same angle made on all parts of the arc. The figure 5 in brackets signifies that the figure 0″·89 is the mean for 5 different angles which were measured on this part of the arc. Means have also been taken out for each row and each column, thus the meaning of –0·22 at the foot of the first column is that all angles which were measured clockwise from between 0° and 10° or 180° and 190° tend to be 0″·22 seconds too small. It is noticeable that the largest figures occur where there are least entries, and it is apparent that if observations are made on 12 zeros, graduation error should have a very small effect. This remark applies to systematic graduation error affecting all the graduations through several degrees. The complete table of Z.M. – G.M. (not printed) shows that individual graduations are also very good. Out of about 300 entries, 65 exceed 1″, 15 exceed 2″ and the largest is 3″·04, and there is no reason to attribute even these wholly to graduation error.

On hearing of the defects of No. 37, Messrs Wild at once offered to replace it free of charge, and its replacement has been received. This theodolite (No. 130) appears to be in excellent order, and a good season's work is confidently expected.

It has not been possible to make extensive tests for astronomical work, but a short azimuth programme with No. 130 has given very satisfactory results. Azimuths from Polaris out of elongation on six different zeros gave results which differed from their mean by –2″·2, +0″·8, –2″·9, +2″·7, +0″·8 and +0″·5 respectively, giving a probable error of the mean of 0″·6. Each of these figures is the mean of a single reading on face left and face right, and the total observing time was 35 minutes, excluding time observations

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TABLE 1.—*Wild Theodolite No. 59.*

Values of ZM − GM, where ZM is the mean value of all measures of an angle taken on a certain part of the circle, and GM is the mean of all the measures on all parts of the circle. Figures in brackets indicate the number of different angles contributing to the means tabulated.

Seconds of Arc.

Part of circle	180-190 0-10	190-200 10-20	200-210 20-30	210-220 30-40	220-230 40-50	230-240 50-60	240-250 60-70	250-260 70-80	260-270 80-90	270-280 90-100	280-290 100-110	290-300 110-120	300-310 120-130	310-320 130-140	320-330 140-150	330-340 150-160	340-350 160-170	350-360 170-180	Mean of rows
180-190 0-10	…	…	…	…	…	…	…	+0·51(1)	+1·30(1)	−0·37(3)	+0·17(1)	+1·05(2)	+0·89(5)	+0·27(3)	−0·33(3)	+0·10(7)	+0·66(3)	…	+0·34
190-200 10-20	−0·62(1)	…	…	…	…	…	…	…	…	…	+0·10(1)	…	+0·48(4)	+0·05(2)	…	−0·01(3)	−0·66(2)	−0·03(1)	+0·01
200-210 20-30	+0·31(1)	…	…	…	…	…	…	…	…	…	…	…	+0·13(1)	−0·12(2)	…	−0·21(2)	+0·85(1)	−0·14(1)	+0·06
210-220 30-40	−0·36(7)	−1·07(3)	…	…	…	…	…	…	…	…	−0·39(1)	−0·56(1)	−0·18(3)	−0·09(1)	+1·72(2)	−0·17(5)	−0·18(3)	+0·24(3)	−0·16
220-230 40-50	−0·24(3)	+0·17(2)	−1·59(1)	−0·20(1)	…	…	…	…	…	…	…	…	…	−0·62(1)	…	−0·41(4)	+0·57(2)	…	−0·24
230-240 50-60	+0·57(2)	+0·97(1)	−0·45(1)	+0·01(1)	…	…	…	…	…	…	…	…	…	…	…	−0·59(1)	−0·05(2)	…	+0·13
240-250 60-70	−0·59(5)	−0·41(3)	+0·00(3)	+0·19(7)	−0·14(3)	…	…	…	…	…	…	…	…	−1·47(1)	−0·74(1)	+0·01(3)	−0·33(1)	+0·64(2)	−0·16
250-260 70-80	−0·10(4)	+0·10(2)	…	−0·04(3)	−1·17(2)	+0·05(1)	+0·37(1)	…	…	…	…	…	…	…	…	…	+0·42(1)	…	−0·13
260-270 80-90	+0·23(1)	+0·39(2)	…	+0·75(2)	−0·19(1)	+0·06(1)	+0·99(1)	…	…	…	…	…	…	…	…	…	…	…	+0·42
270-280 90-100	−0·20(3)	−0·13(1)	−1·22(2)	+0·02(5)	+0·59(3)	+0·70(3)	+0·37(7)	+0·87(3)	…	…	…	…	…	…	…	…	+0·92(1)	+0·69(1)	+0·26
280-290 100-110	…	−0·07(1)	…	−0·28(4)	−1·05(2)	…	+0·30(3)	+1·49(2)	+0·34(1)	−0·19(1)	…	…	…	…	…	…	…	…	+0·05
290-300 110-120	…	…	…	+1·68(1)	−0·13(2)	…	−0·12(2)	+0·34(1)	−0·13(1)	−0·62(1)	…	…	…	…	…	…	…	…	+0·10
300-310 120-130	…	−0·22(1)	−0·14(1)	+0·18(3)	+1·11(1)	−0·57(2)	−0·19(5)	+0·25(3)	−0·54(3)	−0·55(7)	−0·14(3)	…	…	…	…	…	…	…	−0·21
310-320 130-140	…	…	…	…	+0·34(1)	…	+0·75(4)	+0·19(2)	…	−0·11(3)	+0·15(2)	−0·07(1)	+0·04(1)	…	…	…	…	…	+0·26
320-330 140-150	…	…	…	…	…	…	−0·18(1)	+0·05(2)	…	−0·46(2)	−2·68(1)	+0·32(1)	−0·33(1)	…	…	…	…	…	−0·46
330-340 150-160	…	…	…	…	+0·65(1)	−0·28(1)	+0·57(3)	−0·72(1)	−1·88(2)	+0·05(5)	−0·52(3)	−0·09(3)	+0·25(7)	−0·18(3)	…	…	…	…	−0·10
340-350 160-170	…	…	…	…	…	…	…	−0·20(1)	…	−0·46(4)	+0·13(2)	…	+0·10(3)	+0·03(2)	+1·28(1)	+0·58(1)	…	…	+0·03
350-360 170-180	…	…	…	…	…	…	…	…	…	−1·29(1)	−0·13(2)	…	−0·52(2)	+0·69(1)	+0·37(1)	−0·39(1)	…	…	−0·24
Mean of columns	−0·22	−0·10	−0·61	+0·14	−0·09	+0·10	+0·30	+0·42	−0·48	−0·37	−0·28	+0·19	+0·25	−0·08	+0·42	−0·10	+0·19	+0·32	…

and setting up the instrument. It seems probable that a very good geodetic azimuth can be observed in a single night.

In conclusion it is considered that the Precision Wild is capable of carrying out the best primary triangulation, but that something must be done to improve its reliability. Either there must be a great advance in the quality of the materials and in the factory testing (and it is not suggested that either is unduly faulty at present), or else it must be made possible for observers to dismantle their own instruments. It is admittedly bad for a Wild theodolite to be dismantled, but when a triangulator is distant many weeks march from a workshop, he cannot do any further damage to an instrument which will not work. During the present season the Survey of India are using Wilds, but are taking the precaution of carrying 12-inch theodolites into the field, and keeping them within reach of the observers.

APPENDIX

Chittagong Series. Height Computations.

All the vertical angles of the Chittagong series not having been observed at the hours of minimum refraction, a certain amount of irregularity was necessary in the computations, in the form of rejections and corrections to observed values. The details of this work are here put on record, although they are of little general interest. The method used is not intended to form a precedent in geodetic work, in which it is to be hoped that all angles will be observed at times of minimum refraction.

Chart XVII shows the computed differences of height from either end of each side. All afternoon observations on any one day have been meaned together. Where any afternoon observations are available, observations made at other times have been omitted, except when they show less refraction than the afternoon observations, or are otherwise of interest. Observations made at times other than between 13 and 15·30 hours are followed by the hour of observation in brackets. The coefficient of refraction employed in the computations was taken as usual from Table 5 Sur of the Auxiliary tables, which gives a value dependent on the heights of both the station of observation and of the point observed. Inspection of Chart XVII shows that in the east end of the series the height difference from the higher end of a ray is invariably greater than that determined from the lower end. Such discrepancies may of course be caused by deviation of the vertical of the stations concerned, but they would also be caused by a very small inaccuracy in the coefficient of refraction taken from the tables, and the regularity with which the difference occurs indicates that this is the cause. This error is almost entirely cancelled by accepting the mean value as obtained from either end of the ray.

Cases occur (e.g. Yetagong—Mongklang) where a value of the height difference is available at one end of a ray only. Under these circumstances it is not right to accept this value of the height difference; it is better to allow for the error in the assumed coefficient of refraction by improvising a value for the other end of the ray, with which to mean the observed value. This value may be improvised as follows:—The effect of an error in the coefficient of refraction varies as the square of the length of the ray; hence observations from opposite ends of a ray should give a discrepancy of KM^2, where M is the length in miles, and K is a constant determined from the following table.

Ray	Discrepancy (D)	Length (M)	$D/M^2 = K$
	feet	*miles*	
Waibula to Wone-lone-taung	10	25	·016
Yetagong to Wone-lone-taung	8	22	·017
Yetagong to Zemuklang	9	22	·019
Zemuklang to Mongklang	12	18	·037
Zemuklang to Lungleng	40	35	·033
		Mean value of K =	·024

No rays involving Zovailangklang have been included in the above table, because observations there were very discordant.

Examination of Chart XVII shows that at some stations the data are incomplete or discrepant as noted below.

Waibula.—To Wone-lone-taung. No afternoon observations. Accept 1,027·0 to allow for further fall.

Yetagong.—To Zemuklang. No afternoon observations. Accept 1,566·0 to allow for fall.

To Mongklang. No observations. Accept 572·7 – KM^2, i.e. 559·0.

Zovailangklang.—To Zemuklang. No afternoon observations. Accept 212·0 to allow for fall.

To Mongklang. No afternoon observations. Accept 798·0 to allow for fall. The discrepancy between the two ends of the ray is seen to be very large.

To Lungleng. No afternoon observations. Accept 2,676·0 to allow for fall.

To Blue Mountain. No afternoon observations, and the 11.30 hour value is seen to be only 2 feet lower than the 9 hour value, as compared with 25 feet in the ray to Lungleng, and about 17 feet in the ray from Blue Mountain to Zovailangklang. Further the value of 1,107 is only 2 feet greater than the value obtained from the opposite end of the ray.

Accepting the 9 hour value and guessing a fall to midday the value 1,105 + 25 (1,130) is suggested. The 11.30 value suggests 1,110 for midday, and the standard discrepancy from the value obtained at Blue Mountain suggests $1,105 + KM^2$ i.e. 1,124. Accepting the mean of these three gives 1,121, weakly determined.

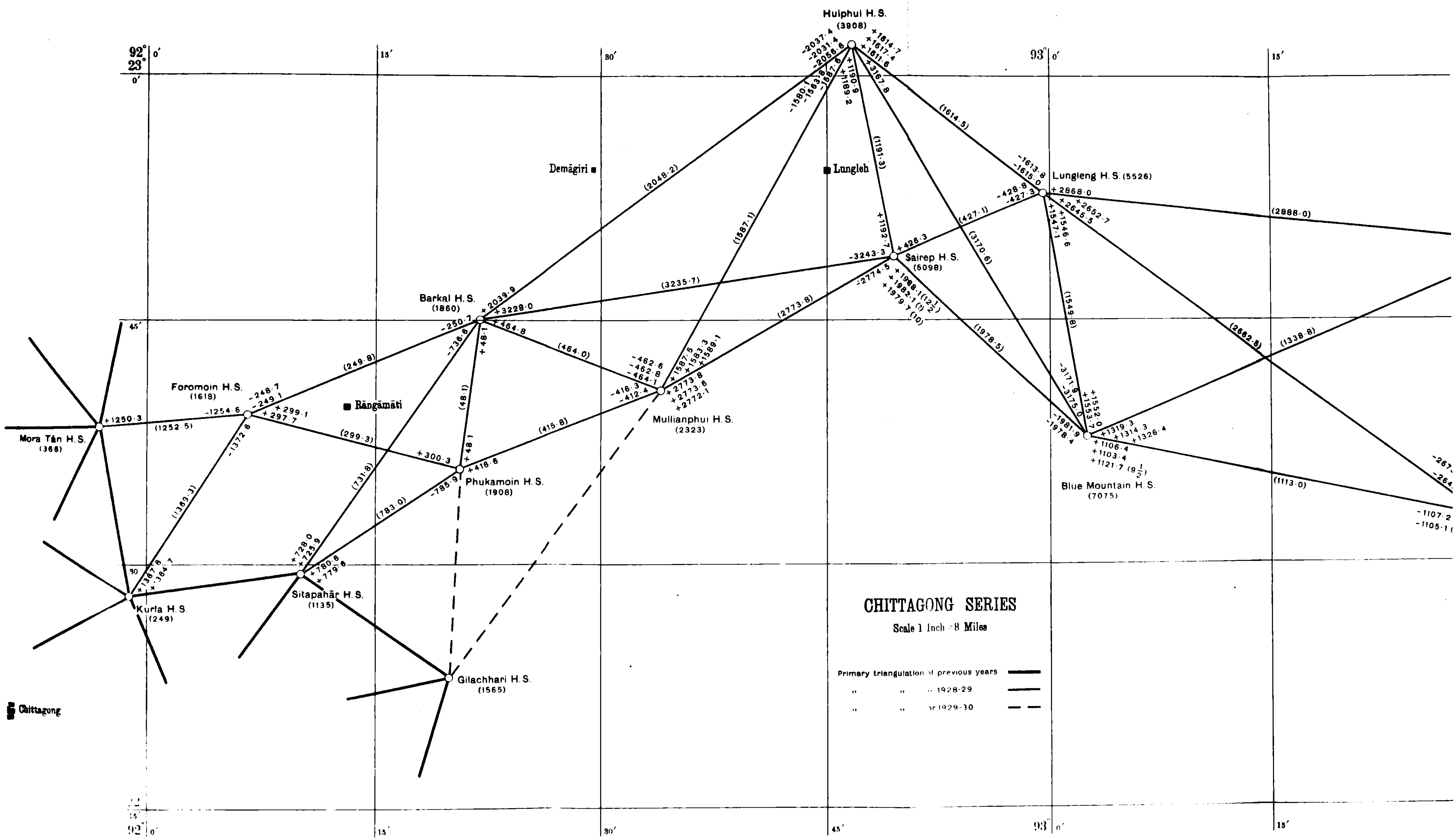
Blue Mountain.—To Zemuklang. The value 1,326·4 was observed at 13.30, but is clearly not a minimum and is rejected, since other lower values are available.

Sairep.—To Blue Mountain. The value 1,988 at 12.30 indicates greater refraction than 1,979 at 10 hours, or than 1,982 at an unrecorded hour. Results obtained at this unrecorded hour for other rays, show that it was an early hour. Consequently the value 1,988 has to be rejected. The value 1,979·7 at 10 hours suggests about 1,977 at midday, which is also in good agreement with 1,981 and 1,978 obtained from Blue Mountain, it being noted that the value of K (see above) is considerably smaller in this part of the series.

Huiphui.—All observations were made in the afternoon but on two days the refraction of the rays to Barkal and Mullianphui is seen to have failed to have reached a minimum. Consequently for these two rays the values 1,587·6 and 2,056·6 are accepted.

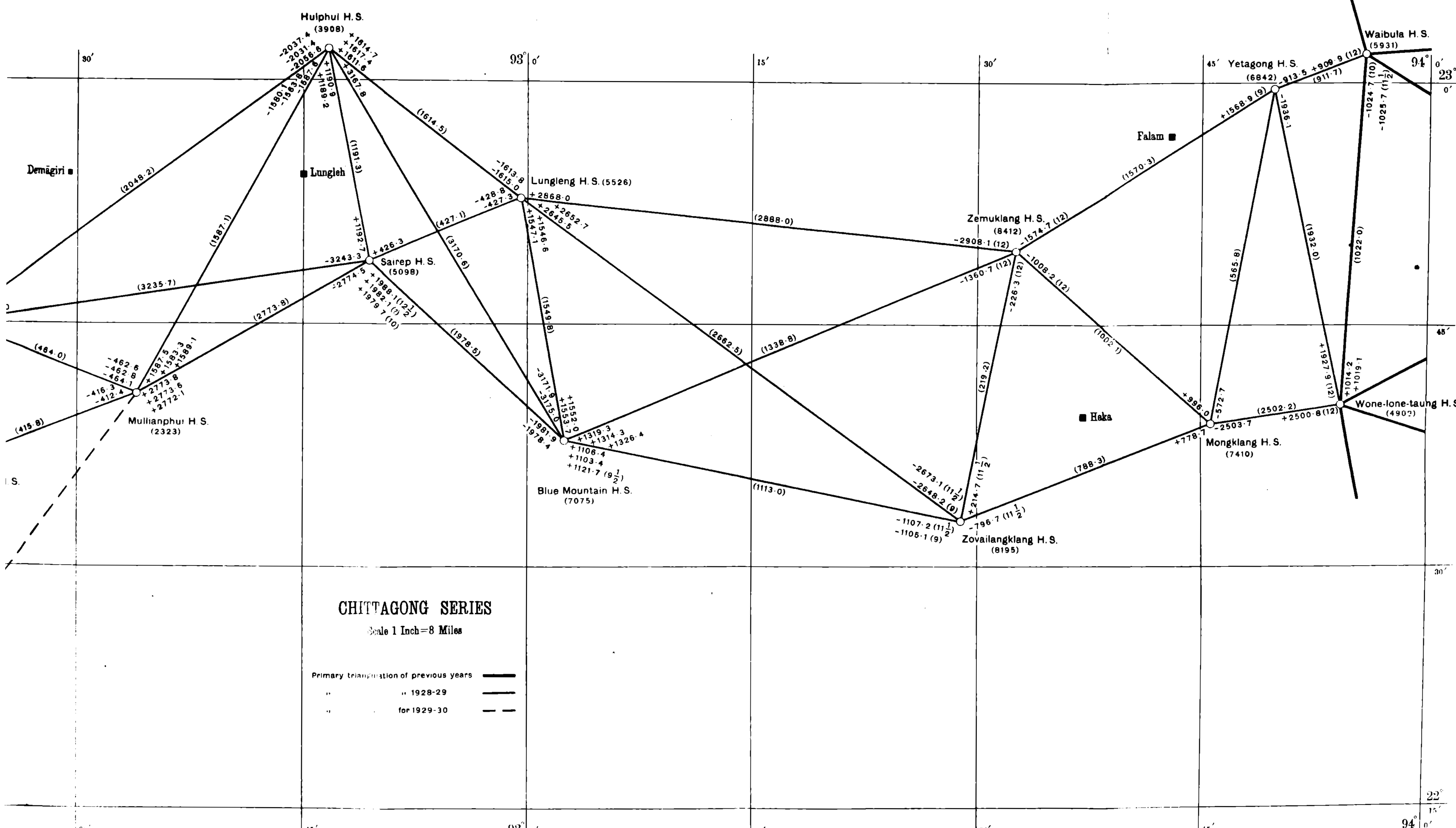
In Chart XVII the values within brackets give the mean of the height differences determined from either end of the ray, as modified in the above notes. The computation of the actual heights of stations then presents no difficulty. When the height of an unknown station is determined from two rays only (as at Yetagong), the mean taken has been weighted somewhat in favour of the shorter ray. Height determinations based on Zovailangklang have been given low weight.

The final closing error in height at Sitapahār, Mora Tān and Kurla is 8 feet, but this cannot all be attributed to the Chittagong series. In the west there is a spirit-levelled connection near Chittagong, but in the east the nearest connection is at Mandalay, so that this 8 feet has been accumulated in the 280 miles of triangulation constituting the Chittagong and Mandalay Longitudinal series. The probable error of height after 280 miles of triangulation is $1{\cdot}3\,P\sqrt{2{\cdot}80}$ feet, where P is a quantity determined from the closures of height round each triangle. (See Geodetic Report Vol. III, 1926-27, Chapter II). In modern primary series P has averaged about 1·5, so that in 280 miles the probable error should be about 3½ feet. The 8 feet actually found is not altogether discordant with this, but the lack of a full set of afternoon observations in the Chittagong series has probably been responsible for some considerable loss of accuracy.



Reg. No. 1811 D.D. 1930-500.

Chart XVII



To accompany Geodetic Report Vol. V

Chart XVIII

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

Heliozincographed at the Survey of India Offices, Dehra Dun.

CHAPTER VI

LEVELLING

BY H. P. D. MORTON

1. Organization.—Eleven detachments were formed and employed as follows:—5 on high precision levelling throughout the season, 1 on high precision levelling up to December 1928 and thereafter on tertiary levelling, 1 on secondary levelling throughout the season, 1 on secondary levelling up to January 1929 and thereafter on tertiary levelling and 3 on tertiary levelling throughout the season.

Secondary work was carried out for the East Indian Railway, and the Punjab and Burma Governments, and tertiary for the latter two Governments and Bombay in connection with the following engineering projects.

Muzaffargarh Indus Canal Area	Punjab.
Protective Works for the Sittang River, and a contour survey of Myanaung Plain	Burma.
Lloyd Barrage	Bombay.

In order to give effect to the accepted policy that the Party should not be encumbered with tertiary levelling which (in the same way as minor triangulation) should be done by Topo. Circles, the four detachments formed for this class of work for the Lloyd Barrage Project were transferred to No. 24 Party, Central Circle. As the Burma Circle was not prepared to take immediate charge of levelling work, the fifth detachment formed for the tertiary levelling of Myanaung Plain worked under the direction of No. 17 Party.

In future all levelling for Local Governments and Public bodies that do not require the accuracy of secondary levelling, will be done by the Topo. Circles concerned.

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

High Precision levelling in fore direction	777	miles	(885 gross)*
,, ,, ,, back	,,	368	,,	(484 gross)
,, ,, ,, both	,,	225†	,,	(232 gross)
,, ,, ,, (revision)	,,	100	,,	(112 gross)
Equivalent total in one direction	...	1,470	,,	(1,713 gross)
Secondary levelling ...	...	930	,,	(1,003 gross)
Tertiary double levelling	...	241	,,	(247 gross)
,, single ,, ...	...		...	1,350 gross

* The first of these figures represents the direct distance levelled between terminal B. Ms. The gross total includes additional check-levelling at ends, and branch lines to G. T. stations etc.

† i.e. 2 × 112½.

3. **Work of detachments.**—*No. 1 detachment* under Mr. L. D. Joshi did the following high precision levelling with a total of 453 miles (494 gross) with 23 miles of relevelments (100°/₀)*

(*a*) Nasīrābād-Bhopāl and Bhopāl-Bīna both in the fore direction; these are parts of new net lines 110 and 109 respectively. The routes were (1) along the main road from Nasīrābād via Būndi, Kotah, Jhālrapātan and Agar to Shujālpur, and thence along the railway to Bhopāl, and (2) partly along the road and partly along the railway from Bhopāl to Bīna.

Six primary bench-marks for the study of seismic changes were made in the neighbourhood of Satur Chhatri, Deoli-Būndi road, Basni, Khera and Rājosi where geological faults are known to exist.

(*b*) Mussoorie via Bhadrāj to Kālsī in the back direction. This is part of the Himālayan circuit Dehra Dūn-Rājpur-Mussoorie-Bhadrāj-Kālsī-Dehra Dūn. Details of this work are given in para 6.

No. 2 detachment under Mr. J. N. Kohli did the following high precision levelling with a total of 408 miles (481 gross) with 19 miles of relevelments (30 °/₀).

(*a*) Mārwār Pāli-Baroda in the fore direction. This comprises parts of the new net lines 103 and 112. The route followed the railway to Mehsāna, thence by road to Viramgām and again along the railway to Baroda via Ahmadābād.

(*b*) Kālsī-Chakrātā in the fore direction along the motor road, and Chakrātā-Mussoorie via Lakhwār in the fore direction along the bridle-path. Details of this work are given in para 6.

No. 3 detachment under Mr. B. P. Rundev did the following high precision levelling with a total of 368 miles (484 gross) with 68 miles of relevelments (18 °/₀).

(*a*) Ghakkar-Amritsar via Lahore in the back direction, along the Grand Trunk Road. This comprises parts of the new net lines 136 and 137.

(*b*) Ludhiāna-Sahāranpur via Ambāla in the back direction, along the Grand Trunk Road to Ambāla and thence to Sahāranpur along the main road. This comprises parts of the new net lines 137 and 139.

(*c*) Meerut-Muttra via Delhi in the back direction, along the main road. This comprises parts of the new net lines 153 and 106.

No. 4 detachment under Mr. Abdul Majid with Mr. I. D. Suri as second leveller was employed on secondary levelling for the East Indian Railway, along the railway from Cawnpore to Allahābād, and

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* When relevelments are expressed as a percentage, this percentage refers to the amount of back levelling only, since it is only on back levelling that relevelments occur.

from Mughal Sarai via the Oudh and Rohilkhand Railway (main-line section) to Najībābād, with a total of 609 miles (641 gross).

No. 5 detachment under Mr. Faizul Hasan with Babu Samiullah Khan as second leveller was employed on the following levelling:—

(*a*) Secondary levelling from Rohilānwāli to Leiah via Alīpur, Ghāzīghāt and Mahmūd Kot for the Muzaffargarh Indus Canal Project. The route was cross-country from Rohilānwāli to Mahmūd Kot, and thence by road to Leiah. Total mileage 225 (239 gross).

(*b*) Secondary levelling along the Zwebut and Pagaing Bunds, and along a cross-country route from Aingdon to Thongwa in connection with certain Protective Works for the Burma Government. Total mileage 96 (123 gross).

(*c*) Tertiary levelling for the Burma Government for a contour survey of the Myanaung Plain. 5 primary and 434 secondary bench-marks were connected, and 10,325 ground-heights were provided for the contour survey. Total double levelling 241 miles (247 gross), and single levelling 1,350 miles.

No. 6 detachment under Mr. Abdul Karim did revision levelling of high precision in Sind from Daur to Bāndhi and Bāndhi to Hyderābād via Daur along the railway line. Total mileage 100 (112 gross), with 55 miles of relevelments (55 %).

On completion of the work this detachment was transferred to No. 24 Party, Central Circle, for employment on tertiary levelling in connection with the Lloyd Barrage Project.

Nos. 7, 8 and 9 detachments were formed for tertiary levelling, and were employed throughout the field season under No. 24 Party. During 1927-28, levelling for the Lloyd Barrage scheme was carried out by No. 17 Party by the methods of secondary levelling, in which one leveller follows another over the same pegs, the second leveller keeping one or two stations behind the first leveller, each using separate pairs of staves. A close network of secondary levelling was already in existence in the area under survey, and as it provided frequent reliable checks for the present levelling, it was considered that if modern Zeiss levels and G.T. staves were used, the desired degree of accuracy could be obtained by the method of tertiary double levelling, in which two levellers work side by side using the same pair of staves, and check each other's values on the spot: moreover, this would result in a considerable saving in establishment, equipment and transport. This method was therefore adopted for the season's work with the approval of the Chief Engineer in charge of the Project.

No. 10 detachment under Mr. N. R. Mazumdar did the following high precision levelling with a total of 105 miles (105 gross) with 8 miles of relevelments (8 %).

(*a*) Dehra Dūn to Kālsī in both directions along the motor road.

(*b*) Kālsī to Mussoorie via Bhadrāj in the fore direction, partly along the foot-path and partly along the bridle-path.

(*c*) Kālsī to Chakrātā in the back direction along the motor road.

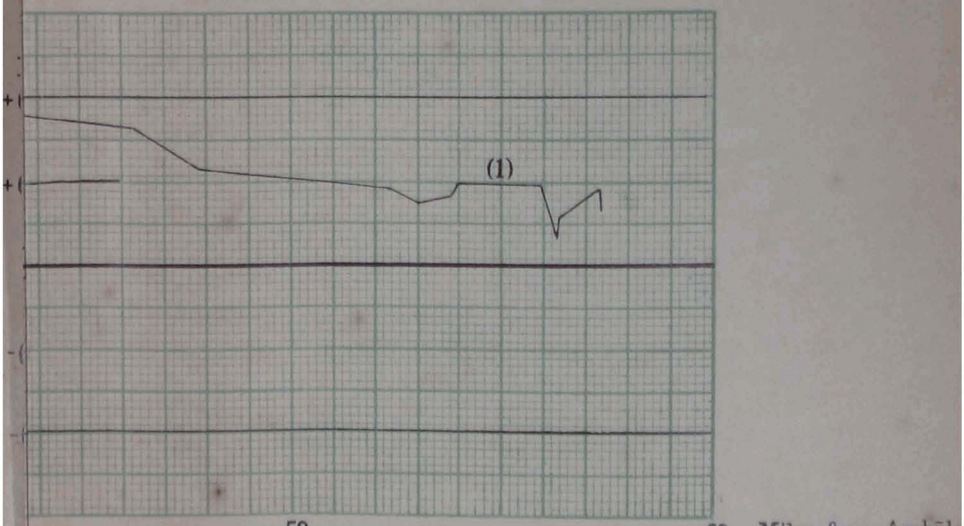
No. 11 detachment under Computer Mohammad Ibrahim did high precision levelling from Mussoorie to Chakrātā via Lakhwār in the back direction along the bridle-path, a total of 36 miles (37 gross) with 15 miles of relevelments (42°/).

4. Subsidence at Ambala.—As mentioned in last year's report the fore levelling between Sahāranpur and Ambāla showed an apparent rise of level of one or two inches between these two places, and a sinking of similar amount at Ambāla. During the season under report the back levelling from Ludhiāna to Sahāranpur has confirmed this, and check lines run from Ambāla for 17 miles towards Kālka and for 46 miles towards Delhi confirm the sinkage at Ambāla. This is not a settlement of a few isolated bench-marks, but a general (although unequal) sinkage of many bench-marks through several miles of line. It must be considered proved that the country round Ambāla has sunk one or two inches since 1910-15, in continuation of the sinkage of 7 inches revealed by the comparison between the 1860-62 and 1912-14 levelling. The apparent rise between Sahāranpur and Ambāla is more likely to be due to subsidence of both these places, than to an actual rise of the intermediate country, although the latter is a possibility. The discrepancies between the old and new levelling are exhibited in Chart XIX.

Reference has been made to the Director of the Geological Survey, who has expressed the opinion that the sinkage is more likely to be due to dewatering by wells, than to general earth movements. Confirmation of this opinion may be obtained by the relative sinkage of bridges and wells between 20 and 35 miles from Ambāla along the road to Ludhiāna. In this section bridge and well bench-marks alternate for several miles, and the wells have generally sunk about half an inch relative to the bridges since 1912-13. This relation cannot be traced elsewhere, but it does indicate that the drawing off of water may under some circumstances cause subsidence ; as is, indeed, obvious.

5. Sukkur-Hyderabad.—For some years discrepancies in the line from Sukkur to Hyderābād have been a source of doubt. It was originally levelled in 1905, and the value then obtained has since been checked by circuits through Kotri and Jacobābād on the one hand, and Barmer and Khānpur on the other, in 1921-25. (See Chart XX). But when the line was relevelled in 1924-25, the fore leveller disagreed with the old levelling by about 2 feet, and the back leveller by about one foot, in the sense that Hyderābād appeared to have sunk.

Chart XIX

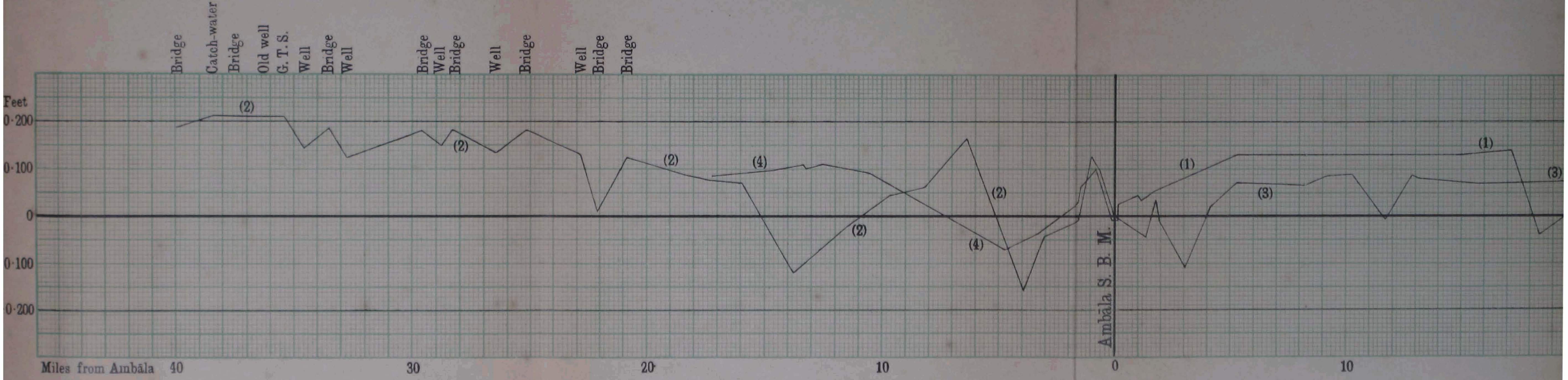


To accompany Geodetic Report Vol. V

SUBSIDENCE AT AMBĀLA

Height by 1927-29 levelling *minus* old levelling

(1) Ambāla to Sahāranpur 1912-13
(2) Ambāla to Ludhiāna 1912-13
(3) Ambāla to Delhi 1915-16
(4) Ambāla to Kālka 1910-11



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A few relevelments were made in 1926-27, which were rather non-committal, giving results in general agreement with the 1924-25 back leveller. The line was relevelled in 1927-28. The northern half was levelled in the fore direction, and agreed reasonably well with the 1924-25 fore and back levellers, who had not disagreed badly with the 1905 work in this section. This section (Sukkur-Bāndhi) may consequently be considered to be satisfactorily completed. The southern half was levelled in the back direction: the result differed from both the 1924-25 levellers, and agreed with the 1905 levelling. In sections of considerable length this old value is further supported by secondary levelling circuits of 1921-22 which were connected with the main line. To complete this half of the work, fore levelling was undertaken in 1927-28, with the expectation that it would confirm the 1905 value: but it has not: it closely agrees with the 1924-25 back leveller.

The relative heights of Sukkur and Hyderābād remain in doubt by one, or even two, feet. No plausible series of earth movements will account for the discrepancies. It is thought that the trouble is probably caused by the instability of the pegs on which the staves are supported, although it is hard to understand why some levellers should have been able to get perfectly accordant results, while others have differed so widely.

It may be noted that with the exception of the levellers marked 7 and 8 in Chart XX, levelling work from south to north has resulted in a lesser difference of height between Sukkur and Hyderābād, than has been derived from levelling carried from north to south. This is especially noticeable in the case of the 1926-27 relevelments, when the effect is separately shown in each of the four sections relevelled. See lines 9 and 10 in Chart XX.

Hyderābād is about 200 miles south of Sukkur, and about 100 feet below it. The levelling follows the railway joining the two places. The country is a flat alluvial plain, liable to a certain amount of flooding.

It is not proposed to undertake further relevelments, as it is evident that accurate results cannot be obtained. It is recommended that the line should be excluded from the level net, although final decision on this point can be postponed until the adjustment of the net is undertaken.

6. **Hill Circuits.**—Levelling in hilly country presents various difficulties which may be expected to lead to some loss of accuracy. The existence of levelling lines from Dehra to Mussoorie and from Dehra to Kālsī (see Chapter VII, Chart XXIV), and the inclusion of a line from Kālsī to Chakrātā in the season's programme, provided an opportunity for closing two hill circuits without great additional labour. Accordingly, levelling was run from Chakrātā to Mussoorie direct, and from Kālsī to Mussoorie via Bhadrāj.

Additional interest was lent to these circuits by the long standing discrepancy (of about 1½ feet) between the height of Mussoorie as obtained by spirit-levelling and by triangulation.

Of the two circuits so formed, the circuit Kālsī-Chakrātā-Mussoorie-Bhadrāj-Kālsī has closed well, the error being 0·057 feet in 83 miles. The circuit Dehra-Kālsī-Bhadrāj-Mussoorie-Rājpur-Dehra has closed badly with an error of 0·658 feet in 66 miles. In this circuit the section Kālsī-Mussoorie is checked by the closure of the other circuit. The section Mussoorie-Rājpur-Dehra is checked by the agreement between the 1905-06 and 1926-27 values, (see Table 5, at end of this chapter), although the 1903-04 values disagree by 0·3 or 0·4 of a foot in the direction required to close the circuit. But in 1905 there was a great earthquake, which levelling for Sahāranpur to Dehra showed to have raised Dehra by about this amount. Doubt is also thrown on the accuracy of this section by the Training School 1926 results which showed an increase of two feet in the upper 2,700 feet of this section, although levelling carried out by officers under instruction is always apt to contain mistakes. It may be noted that the value obtained via Kālsī lessens the disagreement between spirit-levelling and triangulation (see Chapter VII para 9).

The section Dehra-Kālsī disagrees by about 1 foot with the 1905-06 value obtained by officers under instruction (simultaneous double levelling). This section was accordingly suspected of error, but the discordant sections have since been relevelled by officers now under instruction in the Training School, and the 1929 values are upheld. There are thus four independent 1929 values against the one 1905 value, and this section (which is flat and easy) cannot be mistrusted.

It is considered that the error lies in the hill sections, possibly only between Rājpur and Mussoorie, but probably in both sections, the closure of Kālsī-Chakrātā-Mussoorie-Kālsī being accidental.

The following may be considered to be possible sources of error in hill levelling :—

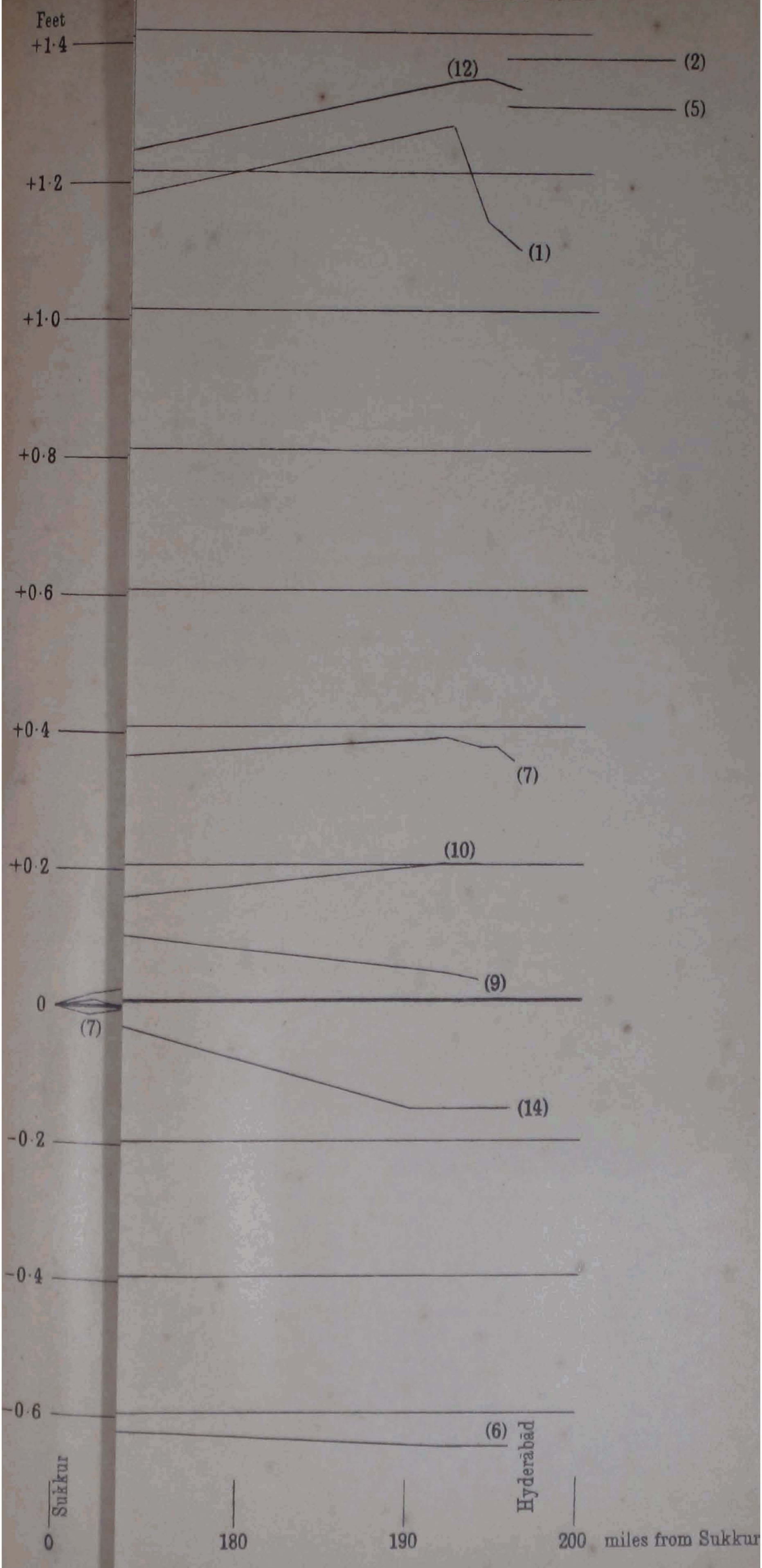
(1) The large number of stations required. But it is generally considered that short shots make for accurate work; one chain shots are probably better than 5 chain shots.

(2) Systematic refraction error. This has been discussed in Professional Paper 22, and found almost negligible.

(3) Discomfort in observing on rough ground, and weariness of the observer. This may perhaps prevent the very best work being obtained, but it should not cause errors of 0·6 of a foot in 60 miles.

(4) The inaccuracy of using hypothetical values of gravity for the dynamic and orthometric corrections. This is discussed in Chapter VII and found to be of little consequence.

Chart XX



To accompany Geodetic Report Vol. V

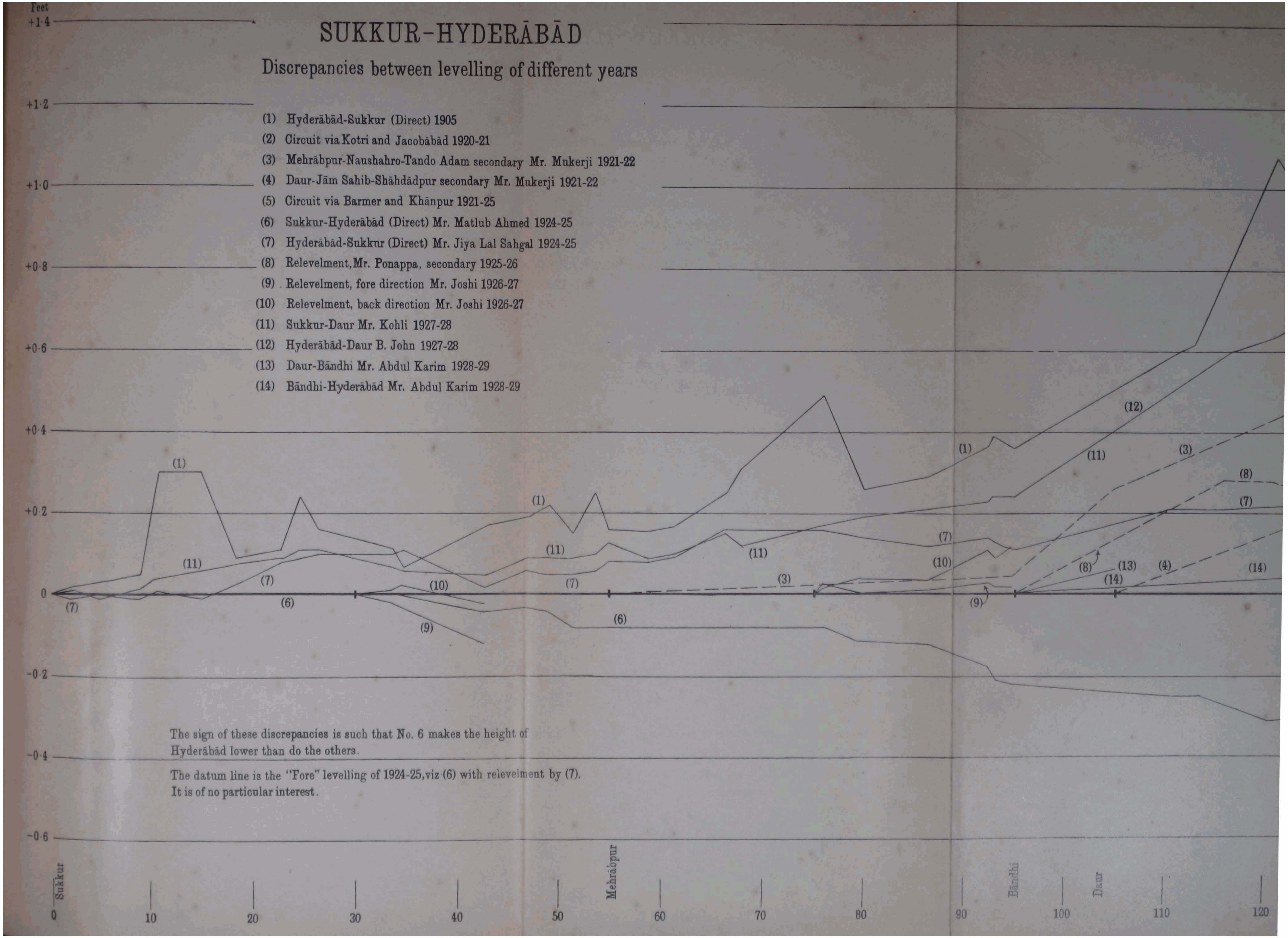
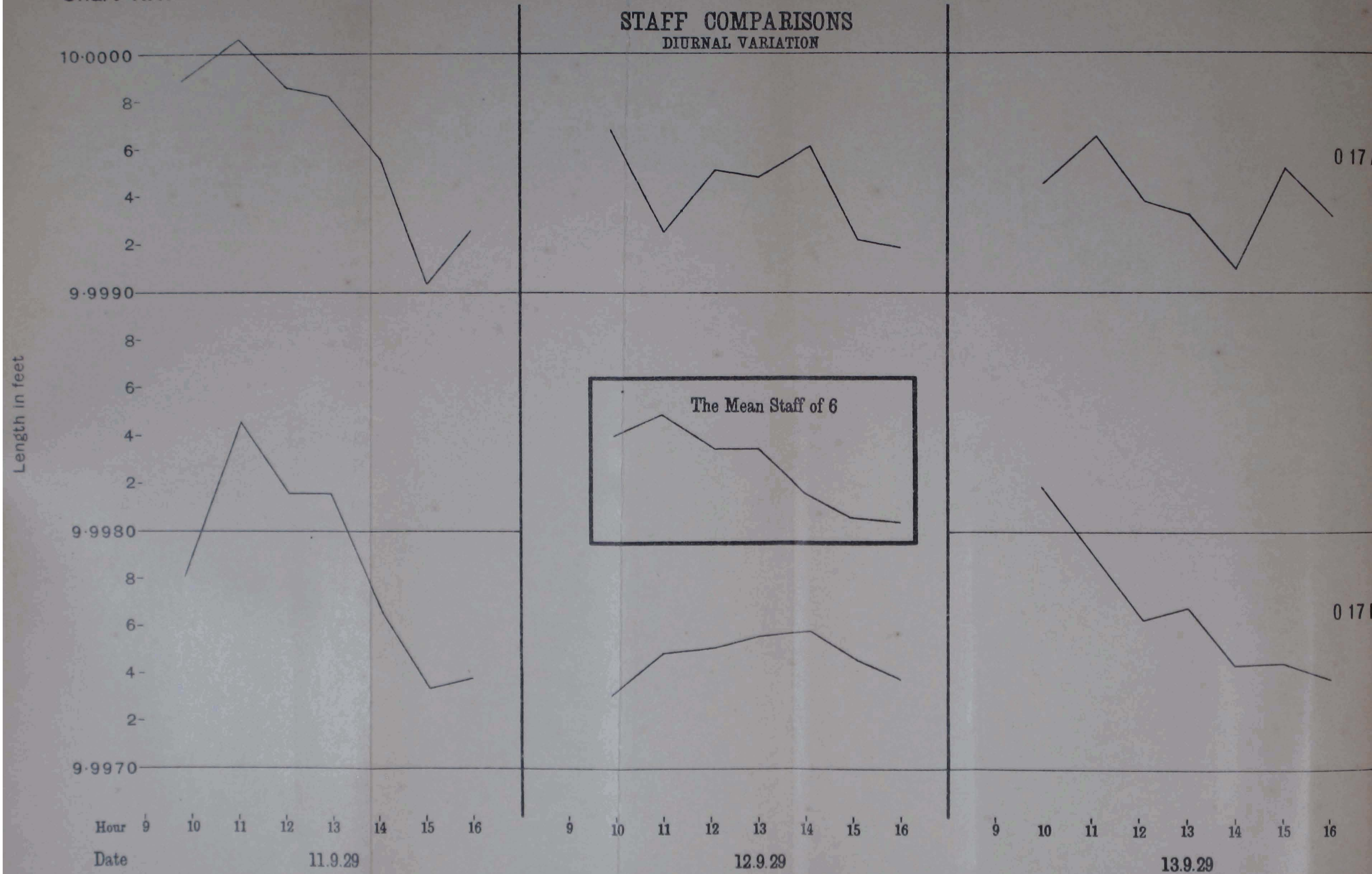

SUKKUR-HYDERĀBĀD
Discrepancies between levelling of different years
(1) Hyderābād-Sukkur (Direct) 1905
(2) Circuit via Kotri and Jacobābād 1920-21
(3) Mehrābpur-Naushahro-Tando Adam secondary Mr. Mukerji 1921-22
(4) Daur-Jām Sahib-Shāhdādpur secondary Mr. Mukerji 1921-22
(5) Circuit via Barmer and Khānpur 1921-25
(6) Sukkur-Hyderābād (Direct) Mr. Matlub Ahmed 1924-25
(7) Hyderābād-Sukkur (Direct) Mr. Jiya Lal Sahgal 1924-25
(8) Relevelment, Mr. Ponappa, secondary 1925-26
(9) Relevelment, fore direction Mr. Joshi 1926-27
(10) Relevelment, back direction Mr. Joshi 1926-27
(11) Sukkur-Daur Mr. Kohli 1927-28
(12) Hyderābād-Daur B. John 1927-28
(13) Daur-Bāndhi Mr. Abdul Karim 1928-29
(14) Bāndhi-Hyderābād Mr. Abdul Karim 1928-29
The sign of these discrepancies is such that No. 6 makes the height of Hyderābād lower than do the others.
The datum line is the "Fore" levelling of 1924-25, viz (6) with relevelment by (7).
It is of no particular interest.
Feet
+1·4
+1·2
+1·0
+0·8
+0·6
+0·4
+0·2
0
-0·2
-0·4
-0·6
Sukkur
Mehrābpur
Bāndhi
Daur
0
10
20
30
40
50
60
70
80
90
100
110
120

Chart XXI



Reg. No. 1823 G.O.O.1830-300.

(5) The length of the staff. This is very important in hill circuits: an error of ·001 in a 10-foot staff will cause an error of 0·5 feet in a 5,000 foot rise. The staves are frequently compared with standard tapes and each comparison is apparently accurate to less than ·001 feet, but it is always possible that the end divisions, to which measures are made, may be slightly discordant with the rest of the staff (see Geodetic Report Vol. III, Chapter III, para 5). Further, the staff comparisons are generally made in the afternoon, and it cannot be said for certain that the staff has the same length while at work. On the contrary, some comparisons made at Dehra throughout the day (see para 7 of this chapter), indicate that there may be an appreciable change of length.

It is considered that the closing error is probably due to ignorance of the staves' length, and it is proposed to relevel the line from Rājpur to Mussoorie with invar staves as soon as possible.

7. Diurnal change of staff lengths.—From time to time the wooden levelling staves are compared with steel tapes, generally after work in the afternoon. The wooden staves are known to have a very small temperature coefficient, but, especially in hill circuits, it is essential to know that the length does not vary from any cause whatsoever. A few comparisons of two staves have been made throughout the day at Dehra Dūn, with the result that a persistent tendency to shorten between morning and afternoon is seen to be possible. See Chart XXI.

In the tests made this shortening averaged ·00036 feet in 10 feet between 10 a.m. and 4 p.m. An error of this magnitude cannot cause an error of 0·6 feet in a rise of 5,000 feet as referred to in para 6, but it is quite possible that the change may be several times greater in other staves and under other circumstances, and wooden staves cannot be considered to be reliable instruments for measuring great heights. The remedy lies in the use of invar staves, which it is hoped to introduce shortly.

8. Probable Errors.—Probable errors of 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
106	Delhi-Muttra ...	± 0·00228	± 0·00038
136	Ghakkar-Lahore ...	± ·00268	± ·00018
137	Ludhiāna-Ambāla .	± ·00234	± ·00150
137	Lahore-Amritsar ..	± ·00263	± ·00006
139	Ambāla-Sahāranpur ...	± ·00283	± ·00043
153	Delhi-Meerut ..	± ·00258	± ·00018
101 A	Bāndhi-Hyderābād ...	± ·00287	± ·00159
61 D	Dehra-Kālsī and Mussoorie ...	± ·00393	± ·00056
61 H	Kālsī-Chakrātā and Mussoorie	± ·00403	± ·00090

Permissible probable accidental and systematic errors are ±·00416, and ± ·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.	Cawnpore-Allahābād ...	± 0·00405
,,	Mughal Sarai-Najībābād	± ·00386
No. 5 Dett	Rohilānwāli-Leiah .	± ·00404
,,	Bridge No. 74-Myitkyo...	± ·00278
,,	Panut-Penwegon .	± ·00512

9. 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.
136	Jhang-Lahore ...	57	Portion Jhang-Lāla Mūsa-Ghakkar not yet completed.
137	Lahore-Ambāla ...	107	The whole line is complete.
139	Ambāla-Morādābād ...	58	Portion Sahāranpur-Morādābād not yet completed.
153	Delhi-Bareilly ...	45	The whole line is complete.
106	Jhang-Muttra ..	101	The whole line is complete.
61 D	Dehra-Kālsī-Mussoorie ...	48	
61 H	Kālsī-Chakrātā-Mussoorie ..	64	
101 A	Sukkur-Hyderābād ...	100	The whole line is complete.
	Total ...	580	
	Previously completed ..	6717*	
	Total completed to date ...	7297	

In addition to the above, 1,080 miles have been completed in one direction only, which is equivalent to 540 miles in both directions, making an equivalent total of 7,837 miles. The total mileage of the net is about 15,900 miles, about 2,600 miles having been added to the figure 13,300 published in Records Volume XV (1919-20), on account of the subsequent inclusion of the lines shown in the following table.

Line	From	To	Miles	Line	From	To	Miles
101 A	Sukkur	Hyderābād	195	Part of 61	Ferozepore	Ludhiāna	78
121 A	Midnapore	Rānīganj	105	61 A	Sahāranpur	Mussoorie	64
150	Kotri	Barmer	210	61 D	Dehra Dūn	Mussoorie via Kālsī	48
151	Rānīganj	Dinājpur	239	61 H	Kālsī	Mussoorie via Chakrātā	64
152	Rājkot	Porbandar	132	Part of 62	Somna	Agra	70
153	Delhi	Bareilly	178	Part of 63	Agra	Gwalior	77
Part of 15	Bellary	Gooty	58	Part of 64	Sītāpur	Lucknow	57
26 B	Bijāpur	Bāgalkot	50	70 B	Aurangābād	Barākar via Rānchī	286
Part of 29 A	Bāgalkot	Raichūr	121	70 C	Barhī	Rānchī	84
54 A	Jacobābād	Quetta	207	Part of 72	Bankipore	Bihta	21
Part of 56	Lahore	Ferozepore	55	...	...	...	...

* Disagrees with previous year's report on account of inclusion of lines Nos. 15, 26B, 29A, 54A, 56, 61, 61A, 61D, 61H, 62, 63, 64, 70B, 70C. 72.

N.B:—The new net is now considered to include pendent lines such as Sahāranpur-Dehra, Kālka-Simla etc., but not short branch-lines connecting G.T. Stations or special S. B. Ms.

TABLE 1.—*Tabular statement of out-turn of work, season 1928-29.*

Detachments and lines levelled	Months	Distance levelled: Main line	Distance levelled: Extras and branch lines	Distance levelled: Total	Total number of feet: Rises	Total number of feet: Falls	Mean number of stations at which the instruments were set up	Number of bench-marks connected: Primary: Rock-cut Protected	Number of bench-marks connected: Primary: Other Primary	Number of bench-marks connected: Secondary
		Mls.	Mls.	Mls.	feet	feet				
No. 1 Detachment.										
Part of line 110 Bhopāl-Nasīrābād (fore)	Oct. 28 to Mar. 29	344	36	380	6,752	7,996	5,288	7	22	525
Part of line 109 Bīna-Bhopāl (fore)	Mar. 29 to April 29	89	2	91	934	1,495	1,152	..	1	114
Part of line 61 D Kālsī-Mussoorie (1) (back)	May 29 to July 29	20	3	23	2,775	7,962	1,750	2	51	53
No. 2 Detachment.										
Line 103 Mārwār Pāli-Viramgām (fore)	Oct. 28 to Feb. 29	237	59	296	5,276	3,490	3,584	2	11	368
Part of line 112 Viramgām-Baroda (fore)	Feb. 29 to April 29	107	11	118	933	787	1,364	...	10	133
Line 61 H Kālsī-Chakrātā & Mussoorie (2) (fore)	April 29 to June 29	64	3	67	12,165	6,732	2,606	1	...	109
No. 3 Detachment.										
Part of line 136 Lahore-Ghakkar (3) (back)	Oct. 28 to Nov. 28	57	13	70	697	727	966	...	5	115
Parts of line 137 Amritsar-Lahore (4) (back)	Nov. 28 to Dec. 28	34	12	46	422	301	606	...	2	66
Ambāla-Ludhiāna (5) (back)	Dec. 28 to Mar. 29	73	...	73	457	373	748	...	4	60
Part of line 139 Sahāranpur-Ambāla (6) (back)	Jan. 29 to Feb. 29	58	6	64	533	503	708	..	1	86

(*Continued*)

(1) Relevelled 23 miles. (2) Relevelled 19 miles. (3) Relevelled 2 miles.
(4) do. 9 miles. (5) do. 22 miles. (6) do. 4 miles.

TABLE 1.—*Tabular statement of out-turn of work, season 1928-29.—(contd.).*

Detachments and lines levelled	Months	Distance levelled: Main line	Distance levelled: Extras and branch lines	Distance levelled: Total	Total number of feet: Rises	Total number of feet: Falls	Mean number of stations at which the instruments were set up	Number of bench-marks connected: Primary: Rock-cut Protected	Number of bench-marks connected: Primary: Other Primary	Number of bench-marks connected: Secondary
		Mls.	Mls.	Mls.	feet	feet				
No. 3 Detachment.—(Contd.)										
Part of line 153 Delhi-Meerut (7) (back)	Feb. 29 to Mar. 29	45	7	52	603	675	696	...	5	101
Part of line 106 Muttra-Delhi (8) (back)	Mar. 29 to April 29	101	13	114	976	1,207	1,254	...	5	169
Check-levelling at Ambāla	Feb. 29 to Mar. 29	63	...	63	369	384	592	...	...	28
No. 4 Detachment.										
Branch line 64 J Cawnpore-Allahābād	Oct. 28 to Nov. 28	128	18	146	938	1,051	1,498	...	4	156
Branch line 70 N Moghal Sarāi-Najībābād	Dec. 28 to May 29	481	14	495	4,125	3,539	4,956	...	6	447
No. 5 Detachment.										
Branch line 55 Q Rohilānwāli-Leiah	Sept. 28 to Nov. 28	225	14	239	1,435	1,313	2,708	...	4	219
Branch line 88 I Bridge No. 74 - Myitkyo	Dec. 28 to Jan. 29	34	20	54	288	285	654	...	...	30
Branch line 88 J Panut-Penwegon	Jan. 29	62	7	69	621	539	1,142	...	...	39
Myanaung Plain Tertiary levelling (double)	Jan. 29	241	6	247	2,363	2,388	3,550	...	1	1,518*
Tertiary levelling (single)	to May 29	1,350	...	1,350	...	...	13.990	...	...	8,953†
No. 6 Detachment.										
Part of line 101 A Bāndhi-Hyderābād (9) (fore & part back)	Oct. 28 to Jan. 29	100	12	112	714	730	1,311	...	3	115

(7) Relevelled 5 miles. (8) Relevelled 26 miles. * 1,372 pegs. *(Continued).*
(9) do. 55 miles. † All pegs.

TABLE 1.—*Tabular statement of out-turn of work, season 1928-29.—(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. 10 Detachment.										
Line 61 D Dehra to Kālsī & Mussoorie (10) (fore & part back)	Feb. 29, Mar. 29 & May 29	76	...	76	9,360	4,192	2,333	2	4	123
Part of line 61 H Kālsī-Chakrātā (11) (back)	April 29	29	...	29	115	5,627	918	1	...	38
No. 11 Detachment.										
Part of line 61 H Chakrātā-Mussoorie (12) (back)	May 29 to July 29	36	1	37	6,797	6,753	2,046	1	...	57

(10) Relevelled 7 miles. (11) Relevelled 49 chains.
(12) do. 15 miles.

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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1928-29	
			miles		*feet*	*feet*	*feet*
		At Ambāla on lines 61 F and 61 G					
73	53 B	S. B. M. at Ambāla ...	0·00	1912-14	0·000	0·000	0 000
74	,,	at laboratory ...	0·31	,,	− 1·797	− 1·692	+0·105
77	,,	on Ry. platform ...	1·53	,,	− 4·493	− 4·428	+0·065
79	,,	on Ry. platform ...	1·67	,,	− 5·358	− 5·327	+0·031
34	,,	on Ry. bridge ...	3·32	1910-11	− 5·553	− 5·590	−0·037
35	,,	on Ry. bridge ..	4·78	,,	− 2·114	− 2·183	−0·069
38	,,	on Ry. bridge ...	10·58	,,	+ 0·076	+ 0·167	+0·091
39	,,	on Ry. bridge ...	12·63	,,	+ 8·042	+ 8·150	+0·108
41	,,	on Ry. platform ...	13·30	,,	+19·947	+20·049	+0·102
40	,,	Embedded at Lālru R. S.	13·33	,,	+14·012	+14·123	+0·111
42	,,	on bridge ...	15·59	,,	+30·828	+30·923	+0·095
43	,,	on bridge ...	17·34	,,	+52·401	+52·479	+0·078
83	,,	on stone flooring ...	1·27	1912-14	+ 8·264	+ 8·217	−0·047
79	,,	on Ry. platform ...	1·67	,,	− 5·358	− 5·327	+0·031
89	,,	on bridge ...	1·86	1915-16	− 1·216	− 1·228	−0·012
90	,,	on bridge ...	3·00	,,	− 1·891	− 2·001	−0·110
91	,,	on well ...	4·14	,,	−10·161	−10·140	+0·021
92	,,	Interred between M.S 116 and 117 ...	5·13	,,	−23·943	−23·872	+0·071
93	,,	on culvert ...	6·81	,,	−19·574	−19·502	+0·072
94	,,	on bridge ...	8·11	,,	−14 538	−14·470	+0·068
95	,,	on well ...	9·29	,,	−32·375	−32·291	+0·084
96	,,	on bridge ...	10·26	,,	−14·922	−14 832	+0·090
97	,,	Interred at M.S. 110 ...	11·75	,,	−38·154	−38 161	−0·007
98	,,	on bridge ...	12·86	,,	−13·686	−13·604	+0·082
99	,,	on bridge ...	13·09	,,	−13·421	−13·341	+0·080
101	,,	on culvert ...	15·61	,,	−37·813	−37·746	+0·067
103	,,	on bridge ..	19·34	,,	−48·387	−48·316	+0·071
104	,,	on bridge ...	20·80	,,	−50·556	−50·488	+0·068
105	,,	Interred at M.S. 100 ..	21·86	,,	−58·380	−58·305	+0·075
107	,,	on bridge ...	25·09	,,	−54·531	−54·465	+0·066
2	53 C	on bridge ..	26·41	,,	−53·874	−53·800	+0·074
4	,,	on bridge ...	28·59	,,	−54·150	−53 993	+0·157
6	,,	on bridge ...	30·43	,,	−52·781	−52·725	+0·056
7	,,	Interred at M.S. 90 ...	31·86	,,	−66·121	−66·132	−0·011
10	,,	on bridge ...	35·35	,,	−67·500	−67·433	+0·067
11	,,	on stone ...	36·25	,,	−70·117	−70 046	+0·071
16	,,	Interred at M.S. 80 ...	41·98	,,	−82·752	−82·666	+0·086
17	,,	on bridge ..	44·15	,,	−61·928	−61·830	+0·098
18	,,	on culvert ...	45·90	,,	−81·164	−81·064	+0·100

(*Continued*).

TABLE 2.—*Check-levelling—(contd.).*

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

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1928-29	
			miles		feet	feet	feet
				At Nasīrābād on line 110.			
47	45 J	Stone step ...	0·00	1920-21	0·000	0·000	0·000
46	,,	Stone step ...	0·09	,,	+ 2·238	+ 2·336	+0·098
45	,,	Interred (Type B) ...	0·14	,,	− 1·086	− 0·973	+0·113
44	,,	Rock ...	2·29	,,	+ 42·929	+ 43·063	+0·134
43	,,	Rock .	4·42	,,	+112·055	+112·170	+0·115
42	,,	Rock ...	5·28	,,	+149·571	+149·684	+0·113
41	,,	Rock ...	6·55	,,	+275·617	+275·697	+0·080
				At Bhopāl on lines 110 and 109.			
24	55 E	Plinth of *masjid* ...	0·00	1909	0·000	0·000	0·000
27	,,	Standard (Type P) ...	1·07	,,	− 82·435	− 82·426	+0·009
28	,,	Stone platform ...	1·93	,,	− 82·635	− 82·626	+0·009
30	,,	Bridge ...	2·73	,,	− 91·893	− 91·890	+0·003
31	,,	Bridge ..	3·49	,,	−104·630	104·618	+0·012
32	,,	Bridge ...	5·24	,,	−108·027	−108·034	−0·007
7	,,	Step of *bāori* .	6·51	1883-84	− 93·779	− 93·761	+0·018
6	,,	Guest house ...	1·46	,,	− 28·534	− 28·540	−0·006
34	,,	Standard (Type P) ..	2·03	1909	+100·828	+100·794	−0·034
				At Bīna on line 109.			
18	54 L	Embedded on well ...	0·00	1898-99	0·000	0·000	0·000
19	,,	Bridge ...	1·96	,,	− 20·896	− 20·888	+0·008
20	,,	Bridge ...	2·56	,,	− 21·202	− 21·197	+0·005
21	,,	Bridge ..	5·33	,,	− 19·121	− 19·124	−0·003
22	,,	Platform coping ..	6·07	,,	− 21·054	− 21·160	−0·106
24	,,	Embedded on well ...	6·11	,,	− 26·590	− 26·589	+0·001
				At Mārwār Pāli on line 103.			
17	45 G	Embedded B.M. ...	0·00	1907-09	0·000	0·000	0·000
16	,,	Masonry block ...	0·25	,,	+ 1·459	+ 1·458	−0·001
15	,,	Masonry block ...	2·38	,,	− 2·605	− 2·605	0·000
14	,,	Masonry block ...	4·42	,,	− 15·004	− 14·989	+0·015
18	,,	Masonry block ...	2·07	,,	+ 18·501	+ 18·515	+0·014
98	,,	Rock ...	9·35	1920-21	+ 46·291	+ 46·278	−0·013

Continued).

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

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

Bench-marks of the original levelling that were connected for check-levelling			Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by			Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	Original levelling	Check-levelling 1928-29	
			miles		*feet*	*feet*	*feet*
		At Viramgām on lines 103 and 112.					
1	46 A	Embedded B.M. ...	0·00	1921-22 &1923-24	0·000	0·000	0·000
110	,,	Stone base of post ...	0·25	,,	+ 1·795	+ 1·789	−0·006
111	,,	Bridge ...	1·91	,,	− 2·765	− 2·311	+0·454
112	,,	Bridge ...	3·86	,,	− 4·454	− 4·346	+0·108
		At Baroda on line 112.					
14	46 F	Embedded B.M. ...	0·00	1909	0·000	0·000	0·000
112	,,	Step of church ...	0·39	,,	− 0·809	− 0·749	+0·060
113	,,	Step of museum ...	1·00	,,	+ 0·449	+ 0·470	+0·021
114	,,	Stone sill ...	1·41	,,	+ 3·216	+ 3·236	+0·020
17	,,	Temple ...	1·74	,,	− 3·395	− 3·400	−0·005
116	,,	Plinth of portico ...	1·87	,,	− 0·836	− 0·815	+0·021
117	,,	Plinth of office ...	2·38	,,	+19·424	+19·443	+0·019
120	,,	Step of office ...	2·49	,,	+20·512	+20·528	+0·016
119	,,	State library ...	2·56	,,	+19·969	+19·984	+0·015
118	,,	Standard (Type P) ...	2·65	,,	+18·122	+18·149	+0·027
		At Ghakkar on line 136.					
78*	43 L	Culvert ...	0·00	1926-27	0·000	0·000	0·000
77*	,,	Bridge ...	0·74	,,	+ 2·352	+ 2·355	+0·003
76*	,,	Boundary pillar ...	2·12	,,	− 8·392	− 8·382	+0·010
75*	,,	Culvert ...	3·17	,,	− 8·594	− 8·586	+0·008
74*	19/43 L	Platform coping ...	3·84	,,	− 1·044	− 1·030	+0·014
73*	18/43 L	Platform coping ...	3·95	,,	− 1·124	− 1·112	+0·012
72*	17/43 L	Embedded B.M. ...	4·03	,,	− 9·062	− 9·049	+0·013
		At Bāndhi on line 101 A.					
34	40 B	Bridge ...	0·00	1924-25 &1927-28	0·000	0·000	0·000
201	,,	Verandah flooring ...	0·37	,,	+ 2·207	+ 2·207	0·000
202	,,	Well ...	0·54	,,	+ 4·030	+ 4·009	−0·021
203	,,	Interred (Type B) ...	0·59	,,	− 0·219	− 0·219	0·000

(*Continued*).

* Serial numbers of line Jhang to Lahore.

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: No.	Degree sheet	Description	Distance from starting bench-mark	Observed height above (+) or below (−) starting bench-mark, as determined by: Date of original levelling	Original levelling	Check-levelling 1928-29	Difference (check − original). The sign + denotes that the height was greater and the sign −, less in 1928-29 than when originally levelled
			miles		*feet*	*feet*	*feet*
			At Hyderābād on line 101 A.				
152	40 C	Rock-cut (Type C) ...	0·00	1909-10	0·000	0·000	0·000
419	,,	Boundary pillar ...	0·02	1924-26	− 0·955	− 0·981	−0·026
418	,,	Stone step of *pião* ...	1·17	,,	−64·121	−64·156	−0·035
417	,,	Pavement of water column	1·90	,,	−62·712	−62·759	−0·047
416	,,	Culvert ...	2·07	,,	−62·366	−62·400	−0·034
161	,,	Standard (Type P) ...	3·15	1909-10	−32·164	−32·238	−0·074
217	,,	Stone step of school ...	4·22	1920-21	−61·399	−61·486	−0·087
33	,,	Bridge ...	4·74	1904-05	−46·297	−46·391	−0·094
			At Kālsī on lines 61 D and 61 H.				
39*	53 F	Bridge ..	0·00	1928-29	0·000	0·000	0·000
38*	,,	Rock ...	0·27	,,	+24·616	+24·619	+0·003
37*	,,	Rock ...	0·30	,,	+21·964	+21·972	+0·008
36*	,,	Culvert ...	0·34	,,	+13·114	+13·126	+0·012
35*	,,	Bridge ...	0·59	,,	− 3·402	− 3·395	+0·007
34*	,,	Bridge ...	1·20	,,	−71·504	−71·482	+0·022
33*	49/53F	Masonry pillar ..	2·25	,,	− 5·711	− 5·688	+0·023
			At Chakrātā on line 61 H.				
7†	53 F	Rock ...	0·00	1928-29	0·000	0·000	0·000
6†	,,	Rock ...	0·09	,,	+ 22·906	+ 22·905	−0·001
5†	,,	Rock ...	0·70	,,	+161·233	+161·245	+0·012
A_4†	,,	Rock ...	0·80	,,	+168·578	+168·587	+0·009
			At Mussoorie on lines 61 D and 61 H.				
157	53 J	Rock ...	0·00	1926-27	0·000	0·000	0·000
154	,,	Masonry pillar ...	0·01	,,	+ 9·016	+ 9·020	+0·004
156	,,	Rock ...	0·03	,,	− 6·444	− 6·445	−0·001
155	,,	Rock ...	0·06	,,	− 5·421	− 5·422	−0·001
153	,,	Pendulum pillar ...	0·09	,,	− 1·865	− 1·867	−0·002
51	,,	Rock ..	0·34	,,	−182·137	−182·143	−0·006
50	,,	Stone step ..	0·48	,,	−276·512	−276·527	−0·015
45	,,	Verandah flooring ...	0·72	,,	−344·492	−344·498	+0·004

* Serial numbers of line Dehra - Kālsī - Mussoorie.

† Serial numbers of line Kālsī - Chakrātā.

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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
				(*Ghakkar to Lahore*) old line 56, *new* 136.			
17	43 L	Embedded at Ghakkar R.S.	0·00	1905-06	0·000	0·000	0·000
8	,,	Embedded at Gujrānwāla R.S. ...	10·24	,,	− 7·817	− 7·755	+0·062
111	44 I	Embedded at Kāmoke R.S.	23·31	,,	− 25·484	− 25·462	+0·022
101	,,	Embedded at Muridke R.S.	36·56	,,	− 47·815	− 47·829	−0·014
160	,,	on platform of station ...	48·92	,,	− 51·280	− 51·410	−0·130
159	,,	on platform of station ...	48·98	,,	− 51·312	− 51·455	−0·143
87	,,	on bridge ...	50·07	,,	− 42·116	− 42·120	−0·004
86	,,	on bridge ...	50·35	,,	− 42·082	− 42·090	−0·008
60	,,	Embedded at Lahore R.S.	56·78	,,	− 42·946	− 42·953	−0·007
				(*Lahore to Amritsar*) old line 56 B, *new* 137.			
60	44 I	Embedded at Lahore R.S.	0·00	1909-10	0·000	0·000	0·000
72	,,	Embedded at Dn. Audit office ...	0·46	,,	− 1·737	− 1·743	− 0·006
75	,,	Embedded at Shālamār Road over bridge ...	1·10	,,	− 2·156	− 2·157	−0·001
74	,,	Embedded at Signal Stores	1·67	,,	− 2·598	− 2·591	+0·007
114	,,	on platform of station ..	6·45	,,	+ 7·603	+ 7·605	+0·002
66	,,	S. B. M. at Lahore ...	9·27	,,	+ 3·137	+ 3·168	+0·031
64	,,	on church step ...	9·40	,,	+ 1·701	+ 1·696	−0·005
63	,,	on marble sill of church...	9·44	,,	+ 2·940	+ 2·943	+0·003
120	,,	Embedded at Jallo R.S.	12·99	,,	+ 12·681	+ 12·677	−0·004
119	,,	on station platform ...	13·06	,,	+ 20·201	+ 20·187	−0·014
130	,,	Embedded at Khāsa R.S.	25·92	,,	+ 29·661	+ 29·692	+0·031
135	,,	on bridge ...	30·05	,,	+ 43·934	+ 43·946	+0·012
134	,,	on platform ...	30·43	,,	+ 46·002	+ 46·014	+0·012
136	,,	on stone pavement ...	31·77	,,	+ 47·888	+ 47·828	−0·060
137	,,	on marble pedestal ...	31·87	,,	+ 48·063	+ 47·998	−0·065
138	,,	on bridge ...	32·43	,,	+ 47·753	+ 47·757	+0·004
139	,,	Interred at Amritsar ...	33·96	,,	+ 49·005	+ 49·000	−0·005
142	,,	on stone seat of gate ...	35·11	,,	+ 53·704	+ 53·707	+0·003
151	,,	on Tung T. S. ...	37·12	,,	+ 51·058	+ 51·055	−0·003
				(*Ludhiāna to Ambāla*) old line 61, *new* 137.			
15	44 N	S.B.M. at Ludhiāna ...	0·00	1913-14	0·000	0·000	0·000
14	,,	on stone step ...	0·04	,,	− 0·879	− 0·850	+0·029
12	,,	on stone ...	0·23	,,	+ 1·091	+ 1·126	+0·035

(*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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
			(Ludhiāna to Ambāla) old line 61, new 137—(contd.).				
13	44 N	on stone ...	0·32	1913-14	+ 3·926	+ 3·954	+0·028
11	,,	on stone ...	0·68	,,	+ 1·628	+ 1·637	+0·009
10	,,	on platform ...	0·95	,,	+ 3·162	+ 3·183	+0·021
75	,,	on platform ...	1·34	,,	+ 1·393	+ 1·395	+0·002
76	,,	on platform ...	1·50	,,	− 2·489	− 2·478	+0·011
7	,,	on bridge ...	4·10	,,	+ 15·432	+ 15·430	−0·002
6	,,	on bridge ..	6·20	,,	+ 26·324	+ 26·331	+0·007
85	,,	on culvert ...	9·68	,,	+ 33·650	+ 33·592	−0·058
87	,,	on bridge ...	10·71	,,	+ 35·536	+ 35·489	−0·047
110	53 B	Stone B. M. at Dorāha ...	14·39	,,	+ 36·189	+ 36·177	−0·012
2	,,	on bridge ...	14·46	,,	+ 52·309	+ 52·314	+0·005
114	,,	on well ...	16·85	,,	+ 45·197	+ 45·132	−0·065
113	,,	on Kado T. S. ...	17·52	,,	+ 56·578	+ 56·490	−0·088
123	,,	on bridge ...	24·19	,,	+ 59·625	+ 59·572	−0·053
132	,,	on bridge ...	33·05	,,	+ 66·563	+ 66·434	−0·129
133	,,	on catch-water well ...	34·42	,,	+ 60·514	+ 60·401	−0·113
134	,,	on bridge ...	35·59	,,	+ 67·629	+ 67·518	−0·111
135	,,	on Kūmra T. S. ...	37·92	,,	+ 66·699	+ 66·560	−0·139
136	,,	on well ...	36·86	,,	+ 61·525	+ 61·416	−0·109
137	,,	on bridge ...	37·55	,,	+ 73·323	+ 73·218	−0·105
138	,,	on well ...	38·55	,,	+ 66·083	+ 65·913	−0·170
139	,,	on bridge ...	39·61	,,	+ 61·550	+ 61·419	−0·131
140	,,	on well ...	40·32	,,	+ 64·537	+ 64·347	−0·190
142	,,	on bridge ...	43·41	,,	+ 65·042	+ 64·913	−0·129
143	,,	on well ...	44·34	,,	+ 63·161	+ 62·997	−0·164
144	,,	on bridge ...	44·73	,,	+ 69·341	+ 69·209	−0·132
145	,,	on well ...	46·58	,,	+ 64·237	+ 64·060	−0·177
146	,,	on bridge ...	47·88	,,	+ 67·105	+ 66·978	−0·127
147	,,	on well ...	50·03	,,	+ 69·137	+ 68·960	−0·177
148	,,	on bridge ..	50·89	,,	+ 76·913	+ 76·606	−0·307
149	,,	on bridge ...	52·06	,,	+ 77·333	+ 77·142	−0·191
150	,,	on bridge ...	53·16	,,	+ 68·744	+ 68·541	−0·203
151	,,	on culvert ...	54·42	,,	+ 76·059	+ 75·838	−0·221
153	,,	on bridge ...	55·85	,,	+ 77·991	+ 77·755	−0·236
154	,,	on culvert ...	57·29	,,	+ 74·880	+ 74·637	−0·243
156	,,	on well ...	59·31	,,	+ 84·185	+ 83·741	−0·444
19	,,	Stone B. M. at Moghal Sarāi	61·03	,,	+ 80·758	+ 80·406	−0·352
158	,,	on well ...	63·36	,,	+ 70·135	+ 69·866	−0·269
160	,,	on bridge ...	64·70	,,	+ 75·570	+ 75·320	−0·250
161	,,	on well ...	66·61	,,	+ 81·497	+ 81·350	−0·147
163	,,	on culvert ...	69·00	,,	+ 90·362	+ 89·888	−0·474
164	,,	on bridge ...	69·56	,,	+ 100·087	+ 99·691	−0·396

(*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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(*Ludhiāna to Ambāla*) old line 61, new 137—(*concld.*).					
35	53 B	on bridge ...	69·71	1913-14	+ 93·047	+ 92·683	−0·358
34	,,	on bridge ...	71·16	,,	+ 89·608	+ 89·282	−0·326
165	,,	on culvert ...	72·05	,,	+ 89·689	+ 89·501	−0·188
71 (20)	,,	on stone step ...	72·98	,,	+ 93·335	+ 93·013	−0·322
73 (22)	,,	S. B. M. at Ambāla ...	73·08	,,	+ 95·161	+ 94·845	−0·316
		(*Ambāla to Sahāranpur*) old line 61, new 139.					
73 (22)	53 B	S. B. M. at Ambāla ...	0·00	1912-13-14	0·000	0·000	0·000
80 (29)	,,	on cement flooring ...	0·86	,,	+ 1·878	+ 1·971	+0·093
81 (30)	,,	on stone ...	1·04	,,	+ 3·143	+ 3·168	+0·025
82 (31)	,,	on stone ...	1·08	,,	+ 2·277	+ 2·360	+0·083
71 (20)	,,	on stone step ...	0·10	,,	− 1·826	− 1·833	−0·007
72 (21)	,,	on memorial plinth ...	0·17	,,	− 1·323	− 1·297	+0·026
76 (25)	,,	on monument stone ...	1·03	,,	− 5·870	− 4·827	+1·043
75 (24)	,,	on stone step ...	1·08	,,	− 5·444	− 5·410	+0·034
85	,,	on masonry platform	1·67	,,	− 8·619	− 8·566	+0·053
86	,,	on bridge ...	5·23	,,	+ 3·263	+ 3·392	+0·129
100 (53)	53 F	Interred at Mulana ...	14·93	,,	+ 14·404	+ 14·527	+0·123
102	,,	on well ...	17·10	,,	+ 17·753	+ 17·887	+0·134
103	,,	on well ...	18·38	,,	+ 17·324	+ 17·286	−0·038
105	,,	on bridge ...	22·85	,,	+ 18·926	+ 19·037	+0·111
106	,,	Interred at Chappar	23·49	,,	+ 20·452	+ 20·475	+0·023
107	,,	on bridge ...	23·79	,,	+ 19·458	+ 19·580	+0·122
108	,,	on bridge ...	24·67	,,	+ 17·214	+ 17·359	+0·145
109	,,	on bridge ...	25·45	,,	+ 22·351	+ 22·485	+0·134
111	,,	on bridge ...	26·85	,,	+ 17·171	+ 17·344	+0·173
112	,,	on bridge ...	27·85	,,	+ 16·578	+ 16·744	+0·166
113	,,	on bridge ...	28·87	,,	+ 15·206	+ 15·352	+0·146
114	,,	on bridge ...	31·22	,,	+ 22·174	+ 22·356	+0·182

(*Continued*).

TABLE 8.—*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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		feet	feet	feet
		(*Ambāla to Sahāranpur*) *old line 61, new 139*—(*contd.*).					
3	53 F	Stone B. M. at Jagādhri ...	31·73	1912-13-14	+ 20·664	+ 20·866	+0·202
115	,,	Interred at Jagādhri ...	31·79	,,	+ 21·969	+ 22·153	+0·184
117	,,	on well ...	32·26	,,	+ 20·630	+ 20·834	+0·204
122	,,	on well ...	33·61	,,	+ 27·074	+ 27·286	+0·212
123 (3)	,,	Stone B. M. at Amadalpur	37·32	,,	+ 3·269	+ 3·489	+0·220
124	,,	Interred at Amadalpur ...	37·37	,,	− 9·391	− 9·193	+0·198
5	,,	Stone B M. at Sarsāwā ...	46·23	,,	− 6·407	− 6·264	+0·143
127	,,	on well ...	47·74	,,	− 7·525	− 7·434	+0·091
74	53 G	on bridge ...	52·17	,,	+ 9·739	+ 9·802	+0·063
75	,,	on bridge ...	52·95	,,	+ 10·365	+ 10·416	+0·051
1	,,	Stone B. M. at Megh Chapar Falls ...	53·63	,,	+ 4·385	+ 4·443	+0·058
76	,,	on bridge ...	53·82	,,	+ 5·026	+ 5·097	+0·071
77	,,	on bridge ...	54·52	,,	+ 7·633	+ 7·701	+0·068
38	,,	in dāk bungalow ...	55·89	,,	− 0·988	− 0·919	+0·069
39	,,	on platform ...	56·18	,,	− 5·056	− 5·044	+0·012
78	,,	on well ...	56·20	,,	− 5·102	− 5·073	+0·029
42	,,	on step of church ...	57·15	,,	+ 0·019	+ 0·081	+0·063
41	,,	S. B. M. at Sahāranpur ...	57·18	,,	− 0·136	− 0·098	+0·038
		(*Delhi to Meerut*) *old line 62A, new 153.*					
183	53 H	S. B. M. at Delhi ...	0·00	1912-13	0·000	0·000	0·000
209	,,	on platform of memorial	1·68	,,	− 67·805	− 67·842	−0·037
80	,,	on step of memorial ...	1·81	,,	− 57·176	− 57·182	−0·006
81	,,	on stone flooring ...	1·85	,,	− 58·262	− 58·270	−0·008
79	,,	on pedestal of memorial	2·19	,,	− 60·839	− 60·855	−0·016
208	,,	on bridge ...	2·61	,,	− 66·574	− 66·107	+0·467
207	,,	on ledge of window ...	2·91	,,	− 69·976	− 69·998	−0·022
206	,,	on Jumna bridge ...	3·44	,,	− 73·457	− 73·476	−0·019
205	,,	on Jumna bridge ...	3·46	,,	− 71·846	− 71·872	−0·026
204	,,	on pedestal of memorial	3·64	,,	− 87·187	− 87·239	−0·052
203	,,	on bridge ...	4·17	,,	− 81·413	− 81·456	−0·043
200	,,	on well ...	6·14	,,	− 87·115	− 87·171	−0·056
198	,,	on well ...	7·77	,,	− 89·753	− 89·830	−0·077
197	,,	on stone pillar ...	8·87	,,	− 87·766	− 87·867	−0·101
196	,,	on well ...	9·93	,,	− 85·747	− 85·835	−0·088
195	,,	on stone pillar ...	10·19	,,	− 82·828	− 82·940	−0·112
192	,,	Interred at toll-bar house	12·33	,,	− 88·756	− 90·805	−2·049
191	,,	on stone flooring ...	12·36	,,	− 85·041	− 85·111	−0·070

(*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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(*Delhi to Meerut*) *old line 62 A, new 153*—(*contd.*).					
190	53 H	on bridge ...	12·88	1912-13	− 84·125	− 84·196	−0·071
189	,,	on bridge ...	12·99	,,	− 72·231	− 72·303	−0·072
188	,,	on bridge ..	13·55	,,	− 79·860	− 79·933	−0·073
187	,,	on culvert ...	13·89	,,	− 75·398	− 75·476	−0·078
409	,,	Interred at Ghāziābād ...	13·96	,,	− 70·887	− 70·996	−0·109
410	,,	Step of verandah ...	13·98	,,	− 66·627	− 66·704	−0·077
183	,,	on bridge ...	14·49	,,	− 67·810	− 67·883	−0·073
182	,,	on bridge ...	15·42	,,	− 58·657	− 58·721	−0·064
181	,,	on well ...	15·86	,,	− 57·456	− 57·533	−0·077
180	,,	on culvert ...	16·78	,,	− 50·177	− 50·220	−0·043
178	,,	on stone pillar ...	17·54	,,	− 54·379	− 54·418	−0·039
176	,,	on well ...	17·98	,,	− 57·522	− 57·560	−0·038
173	,,	on bridge ...	19·74	,,	− 50·396	− 50·424	−0·028
168	,,	on culvert ...	22·49	,,	− 46·593	− 46·623	−0·030
166	,,	on culvert ...	23·14	,,	− 46·828	− 46·829	−0·001
165	,,	Interred at Murādnagar ...	23·23	,,	− 52·672	− 52·678	−0·006
164	,,	on culvert ...	23·63	,,	− 50·348	− 50·354	−0·006
161	,,	on lock ...	25·02	,,	− 36·728	− 36·748	−0·020
160	,,	on culvert ...	25·29	,,	− 41·769	− 41·799	−0·030
159	,,	on culvert ...	26·66	,,	− 37·120	− 37·141	−0·021
158	,,	on culvert ...	27·48	,,	− 37·869	− 37·915	−0·046
155	,,	on bridge ...	30·40	,,	− 39·580	− 39·632	−0·052
153	,,	on culvert ...	31·37	,,	− 38·204	− 38·252	−0·048
152	,,	on culvert ...	31·75	,,	− 36·277	− 36·319	−0·042
149	,,	Interred at Muhiuddinpur ·	33·79	,,	− 41·947	− 42·000	−0·053
147	,,	on well ...	35·43	,,	− 29·996	− 30·046	−0·050
144	,,	on well ...	37·75	,,	− 31·752	− 32·071	−0·319
142	,,	on step ...	39·14	,,	− 25·294	− 25·353	−0·059
141	,,	on stone pillar ...	39·25	,,	− 30·213	− 30·257	−0·044
140	,,	on stone pillar ...	39·47	,,	− 31·457	− 31·562	−0·105
133	,,	on stone pillar ...	40·42	,,	− 26·246	− 26·373	−0·127
134	,,	on stone pillar ...	40·47	,,	− 25·729	− 25·819	−0·090
135	,,	on stone pillar ...	40·52	,,	− 25·705	− 25·815	−0·110
130	,,	on drain ...	41·88	,,	− 27·701	− 27·786	−0·085
129	,,	on stone step ...	42·09	,,	− 25·999	− 26·091	−0·092
128	,,	on stone footing ...	42·15	,,	− 24·162	− 24·267	−0·105
29	53 G	on bridge ...	43·27	,,	− 23·689	− 23·798	−0·109
72	,,	on mile pillar ...	43·70	,,	− 25·769	− 25·859	−0·090
28	,,	on culvert ...	44·03	,,	− 22·373	− 22·509	−0·136
26	,,	on stone flooring ...	44·52	,,	− 19·113	− 19·226	−0·113
27	,,	S.B.M. at Meerut ...	44·58	,,	− 20·413	− 20·543	−0·130
126	53 H	on bridge ...	43·93	,,	− 28·146	− 28·249	−0·103
184	53 G	on stone flooring ...	44·10	,,	− 29·757	− 29·877	−0·120

(*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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(Delhi to Meerut) old line 62 A, new 153—(concld.).					
125	53 H	on stone step ...	44·25	1912-13	− 30·204	− 30·321	−0·117
123	„	on stone flooring ...	44·28	„	− 29·217	− 29·330	−0·113
122	„	on stone flooring ...	44·34	„	− 27·610	− 27·705	−0·095
183	53 G	on stone flooring ...	44·58	„	− 24·938	− 25·054	−0·116
120	53 H	on stone flooring .	44·77	„	− 25·386	− 25·492	−0·106
121	„	on stone flooring ...	44·83	„	− 27·939	− 28·052	−0·113
124	„	S.B.M. in P.W.D. office ...	45·03	„	− 27·068	− 27·219	−0·131
185	53 G	on bridge ...	45·94	„	− 25·974	− 26·076	−0·102
187	„	on well ...	46·94	„	− 20·542	− 20·641	−0·099
189	„	on stone pillar ...	48·02	„	− 20·923	− 21·424	−0·501
190	„	on stone pillar ...	48·08	„	− 21·315	− 21·035	+0·280
191	„	on culvert ...	48·14	„	− 18·985	− 19·089	−0·104
194	„	on culvert ...	49·73	„	− 21·376	− 21.472	−0·096
195	„	on bridge ...	50·27	„	− 16·667	− 16·760	−0·093
196	„	on Saini T.S. ...	50·59	„	+ 19·467	+ 19·384	−0·083
		(Delhi to Muttra) old line 62 B, new 106.					
83	53 H	S.B.M. at Delhi ...	0·00	1912-13	0·000	0·000	0·000
84	„	on Pīrgbaib T.S. ...	0·94	„	+ 29·992	+ 29·997	+0·005
85	„	on King Asoka's pillar ...	1·20	„	+ 33·437	+ 33·442	+0·005
86	„	on memorial ...	1·40	„	+ 34·941	+ 34·948	+0·007
87	„	on memorial ...	1·42	„	+ 34·222	+ 34·226	+0·004
269	„	on rock in situ ...	1·72	„	− 27·269	− 27·272	−0·003
262	„	on Lāl Chabūtra ...	8·71	„	− 62·639	− 62·651	−0·012
263	„	on *pião* ...	9·97	„	− 82·094	− 82·119	−0·025
264	„	on temple ...	10·37	„	− 80·370	− 80·385	−0·015
265	„	on stone pillar ...	10·98	„	− 63·599	− 63·583	+0·016
266	„	on stone flooring ...	11·15	„	− 61·349	− 61·335	+0·014
267	„	on stone coping of gate ...	11·17	„	− 61·317	− 61·303	+0·014
68	„	on stone flooring ...	12·46	„	− 64·135	− 64·129	+0·006
69	„	on stone flooring ...	12·65	„	− 62·802	− 62·784	+0·018
70	„	on stone step ...	12·74	„	− 60·420	− 60·403	+0·017
71	„	on marble plinth ...	12·82	„	− 63·010	− 62·992	+0·018
75	„	on marble step ...	13·86	„	− 48·634	− 48·621	+0·013
76	„	on marble step ...	13·90	„	− 50·668	− 50·663	+0·005
67	„	on stone step ...	14·82	„	− 51·699	− 51·713	−0·014
79	„	on pedestal of memorial	15·16	„	− 60·839	− 60·841	−0·002
261	„	at *pião* ...	9·21	„	− 71·609	− 71·657	−0·048
259	„	on bridge ...	10·72	„	− 77·418	− 77·440	−0·022

(*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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(Delhi to Muttra) old line 62 B, new 106—(contd.).					
256	53 H	on wall ...	11·64	1912-13	− 74·724	− 74·777	−0·053
255	"	on reservoir ...	12·60	"	− 62·536	− 62·598	−0·062
254	"	on rock in situ ..	13·88	"	− 52·984	− 53·038	−0·054
252	"	on rock in situ ...	16·43	"	− 61·969	− 62·059	−0·090
251	"	Interred at mile 78 ...	16·62	"	− 70·499	− 70·600	−0·101
250	"	on flooring ...	17·71	"	− 63·246	− 63·341	−0·095
249	"	on well ...	19·00	"	− 80·128	− 80·229	−0·101
248	"	on bridge ...	20·38	"	− 72·511	− 72·602	−0·091
247	"	on bridge ...	20·83	"	− 72·495	− 72·578	−0·083
246	"	on well ...	22·19	"	− 85·163	− 85·243	−0·080
243	"	on well ...	24·14	"	− 93·897	− 94·009	−0·112
241	"	Interred at mile 68 ...	26·90	"	−101·499	−101·604	−0·105
240	"	on flooring ...	28·82	"	−105·059	−105·180	−0·121
239	"	on culvert ...	28·88	"	−103·392	−103·507	−0·115
238	"	on flooring .	30·01	"	−104·109	−104·217	−0·108
237	"	on stone coping f platform	30·33	"	−106·452	−106·563	−0·111
236	"	on well ...	31·39	"	−109·506	−109·644	−0·138
235	"	on culvert ...	31·79	"	−110·838	−110·964	−0·126
234	"	on well ...	32·30	"	−100·767	−100·903	−0·136
233	"	on well ...	33·77	"	−115·107	−115·266	−0·159
231	"	on stone coping of platform	35·98	"	−118·619	−118·744	−0·125
230	"	Interred at mile 58 ...	37·23	"	−123·714	−123·830	−0·116
229	"	on well ...	38·53	"	−114·897	−115·002	−0·105
228	"	on well ...	38·86	"	−113·521	−113·673	−0·152
227	"	on well ...	40·49	"	−112·645	−112·747	−0·102
223	"	on well ...	43·41	"	−116·375	−116·626	−0·251
222	"	on stone flooring ...	43·80	"	−115·295	−115·376	−0·081
219	"	on bridge ...	47·33	"	−110·063	−110·157	−0·094
218	"	Interred at mile 48 ...	47·59	"	−123·556	−123·664	−0·108
216	"	on well ...	50·43	"	−120·536	−120·669	−0·133
215	"	on mile-stone ...	51·70	"	−129·422	−129·487	−0·065
213	"	on well ..	52·20	"	−132·482	−132·604	−0·122
210	"	on lock ...	54·66	"	−121·088	−121·155	−0·067
97	54 E	on rock in situ ...	55·60	"	−120·988	−121·042	−0·054
214	53 H	on Pāhera T.S. ...	55·83	"	− 57·195	− 57·239	−0·044
212	"	on well ..	52·78	"	−129·251	−129·367	−0·116
96	54 E	on block ...	55·98	"	−132·865	−132·952	−0·087
95	"	Interred at mile 38 ...	57·76	"	−139·746	−139·799	−0·053
94	"	on well ...	58·88	"	−138·907	−138·897	+0·010
93	"	on well ...	60·81	"	−138·103	−138·148	−0·045
92	"	on well ...	61·90	"	−140·530	−140·582	−0·052
91	"	on well ...	62·37	"	−140·920	−140·958	−0·038
90	"	on well ...	62·90	"	−139·802	−139·882	−0·080

(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 1928-29 than when originally levelled
No.	Degree sheet	Description		Date of original levelling	From published heights	From revision 1928-29 (unadjusted)	
			miles		*feet*	*feet*	*feet*
		(Delhi to Muttra) old line 62 B, new 106—(concld.).					
89	54 E	on bridge ...	65·06	1912-13	−136·597	−136·653	−0·056
88	"	on stone pillar ...	65·74	"	−142·634	−142·679	−0·045
85	"	on stone slab ...	68·82	"	−139·499	−139·535	−0·036
84	"	on culvert ...	69·99	"	−146·803	−146·840	−0·037
83	"	on stone coping of gate ...	70·28	"	−143·569	−143·655	−0·086
82	"	on step ...	70·68	"	−143·168	−143·210	−0·042
81	"	on stone flooring ...	70·94	"	−145·325	−145·370	−0·045
80	"	on stone step ...	71·10	"	−144·992	−145·035	−0·043
79	"	on stone coping ...	71·42	"	−140·319	−140·389	−0·070
78	"	on bridge ...	72·10	"	−124·414	−124·455	−0·041
77	"	on stone slab ...	72·14	"	−133·247	−133·320	−0·073
76	"	on stone flooring ...	72·33	"	−146·126	−146·186	−0·060
75	"	on bridge ...	72·43	"	−141·514	−141·562	−0·048
74	"	on stone pillar ...	75·92	"	−146·234	−146·250	−0·016
73	"	Interred at Chhāta ...	77·71	"	−150·102	−150·110	−0·008
72	"	on stone ...	77·76	"	−146·491	−146·493	−0·002
71	"	on mile-stone ...	78·46	"	−148·845	−149·458	−0·613
70	"	on well ...	78·52	"	−150·153	−150·179	−0·026
69	"	on mile-stone ...	79·48	"	−148·685	−149·140	−0·455
68	"	on mile-stone ...	80·50	"	−150·043	−150·860	−0·817
67	"	on mile-stone ...	82·52	"	−152·807	−152·828	−0·021
65	"	on bridge ...	85·46	"	−146·744	−146·777	−0·033
64	"	on well ...	86·49	"	−156·276	−156·269	+0·007
63	"	Interred at Chaumа ...	86·58	"	−161·348	−161·341	+0·007
60	"	on bridge ...	88·40	"	−156·398	−156·392	+0·006
54	"	on bridge ...	92·11	"	−167·401	−167·419	−0·018
52	"	on mile-stone ...	93·79	"	−166·020	−166·242	−0·222
51	"	on stone pillar ...	94·47	"	−169·673	−169·672	+0·001
49	"	on well ...	95·55	"	−179·240	−179·250	−0·010
48	"	on stone plinth of wall ...	95·89	"	−199·794	−199·826	−0·032
44	"	on stone plinth of wall ...	97·12	"	−179·750	−179·769	−0·019
43	"	on sill of gate ...	97·98	"	−185·867	−185·890	−0·023
42	"	on well ...	98·34	"	−184·297	−184·322	−0·025
24	"	on platform coping ...	99·11	"	−176·234	−176·260	−0·026
107	"	on culvert ...	100·11	"	−178·429	−178·475	−0·046
108	"	on culvert ...	100·82	"	−176·105	−176·147	−0·042
162	"	at Civil Surgeon's bungalow	98·73	"	−185·240	−185·269	−0·029
19	"	Embedded at Muttra Cantt. R.S. ...	98·98	"	−184·114	−184·145	−0·031
20	"	on platform Muttra Cantt. R.S. ...	99·03	"	−184·290	−184·309	−0·019
21	"	on culvert ...	99·60	"	−192·137	−192·152	−0·015
40	"	on stone flooring ...	100·43	"	−195·782	−195·805	−0·023
25	"	S.B.M. at Muttra ...	100·46	"	−197·817	−197·837	−0·020

(*Continued*).

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

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

No.	Degree sheet	Description (Bench-marks of the original levelling that were connected during the revisionary operations)	Distance from starting bench-mark	Date of original levelling	From published heights (Difference between orthometric heights, above (+) or below (−) the starting bench-mark)	From revision 1927-29 (unadjusted)	Difference (revision − original). The sign + denotes that the height was greater and the sign −, less in 1927-29 than when originally levelled
			miles		*feet*	*feet*	*feet*
		(*Bāndhi to Hyderābād*) *old line 52, new 101 A.*					
34	40 B	on culvert ...	0·00	1904-05-06	0·000	0·000	0·000
16	„	Embedded at Nawāb Shāh R.S. ...	26·09	„	− 24·057	− 24·688	−0·631
7	„	Embedded at Sarhari R.S.	37·13	„	− 31·388	− 31·855	−0·467
5	„	on culvert ...	39·15	„	− 37·318	− 37·671	−0·353
2	„	Embedded at Lundo R.S.	43·62	„	− 34·026	− 34·370	−0·344
225	40 C	on bridge ...	45·25	1921-22	− 40·331	− 40·569	−0·238
219	„	on culvert ...	47·12	„	− 42·839	− 43·312	−0·473
78	„	Embedded at Tando Adam R.S. ...	63·23	1904-05-06	− 47·682	− 48·135	−0·453
52	„	on bridge ...	95·65	„	− 47·040	− 47·946	−0·906
157	„	on stone pavement ...	97·63	„	− 34·109	− 35·027	−0·918
31	„	Embedded at Hyderābād	97·79	„	− 20·892	− 21·812	−0·920
159	„	on stone plinth ...	97·95	„	− 29·304	− 30·215	−0·911
160	„	on stone sill of door ...	98·32	„	− 28·137	− 29·043	−0·906
161	„	S.B.M. at Hyderābād church ...	98·38	„	− 28·762	− 29·667	−0·905
155	„	on stone step ...	99·73	„	− 9·568	− 10·481	−0·913
156	„	on verandah ...	99·82	„	− 9·202	− 10·113	−0·911
154	„	on stone step ...	99·99	„	− 7·491	− 8·390	−0·899
217	„	on stone step ...	99·44	1920-21	− 57·997	− 58·913	−0·916
33	„	on bridge ...	99·96	1904-05-06	− 42·895	− 43·815	−0·920
416	„	on culvert ..	99·46	1924-25-26	− 58·964	− 59·829	−0·865
417	„	at base of water-column ...	99·63	„	− 59·310	− 60·183	−0·873
418	„	on step ...	100·36	„	− 60·719	− 61·590	−0·871
419	„	on M.B. pillar ...	101·51	„	+ 2·447	+ 1·601	−0·846
152	„	Type C at Ganjo Takkar hill ...	101·53	1904-05-06	+ 3·402	+ 2·582	−0·820
		(*Dehra Dūn to Kālsī*) *old line 61 D.*					
10	53 J	Shaw's Refraction station, Dehra Dūn ...	0·00	1908	0·000	0·000	0·000
9	„	S.B.M., Dehra Dūn ...	0·02	„	+ 1·587	+ 1·585	−0·002
12	„	Iron plug, Dehra Dūn ...	0·19	„	− 5·769	− 5·775	−0·006
6	„	S.B.M., Dehra Dūn ...	0·25	„	− 2·767	− 2·760	+0·007
129	53 F	Bridge at Kaulāgir ...	4·93	„	−155·255	−155·230	+0·025
44	„	Pillar at Tons river ...	6·97	„	−343·651	−343·600	+0·051
47	„	Pillar at Sahaspur ...	16·83	„	−630·474	−629·523	+0·951
49	„	Pillar at Ambāri ...	24·94	„	−630·065	−629·064	+1·001

TABLE 4.—*List of triangulation stations connected by spirit-levelling, season 1928-29.*

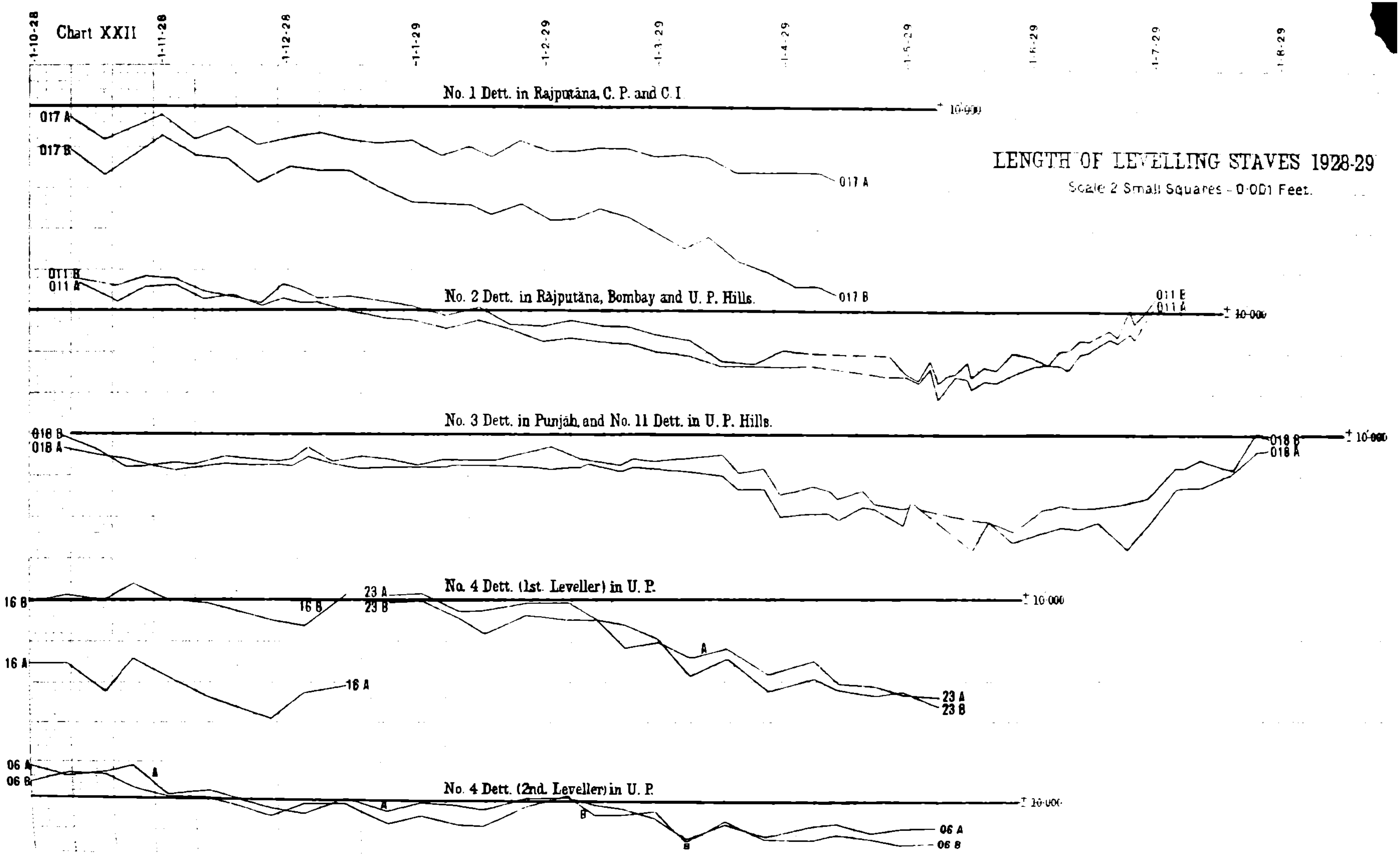
Name of station	Height above mean sea-level		Difference (Trian.—Levelling)	Remarks
	Spirit-levelling	Triangulation		
	feet	*feet*	*feet*	
Gurhāgarh Meridional Series.				
Tung T.S. Lat. 31° 39′ 17″·24 Long. 74 54 30·07	756·397	758	+2	Ground floor mark-stone
Rahūn Meridional Series.				
Kado T.S. Lat. 30° 46′ 37″·21 Long. 76 3 3·20	863·288	864	+1	Ground floor mark-stone
Kūmra T.S. Lat. 30° 37′ 20″·23 Long. 76 18 2·75	873·476	873	0	Ground floor mark-stone
Great Arc Meridional Series, Section 24°-30°.				
Saini T.S. Lat. 29° 2′ 20″·11 Long. 77 47 22·70	776·962	782	+5	Ground floor mark-stone
Pīrghaib T.S. Lat. 28° 40′ 35″·09 Long. 77 12 52·03	787·477	794	+7	Ground floor mark-stone
Pāhera T.S. Lat. 28° 2′ 49″·05 Long. 77 17 23·14	700·367	710	+10	Ground floor mark-stone
Great Indus Series.				
Thal Megrāj T.S. Lat. 29° 15′ 36″·42 Long. 70 38 18·34	322·209	319	−3	Ground floor mark-stone
Khemwāla T.S. Lat. 30° 9′ 45″·76 Long. 70 56 46·32	408·961	409	0	Ground floor mark-stone

(Continued).

Chart XXII

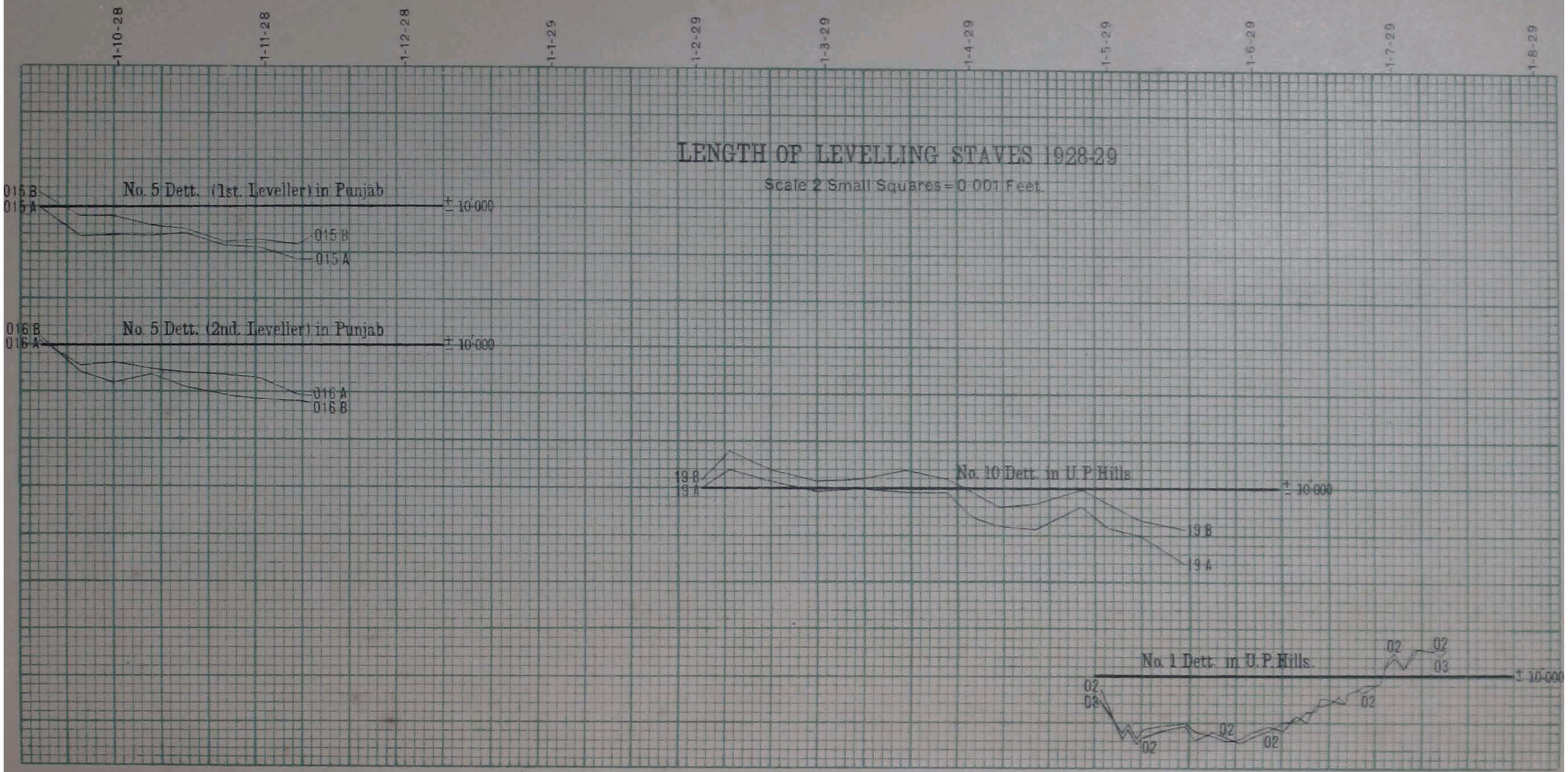
LENGTH OF LEVELLING STAVES 1928-29

Scale 2 Small Squares - 0·001 Feet.



Reg. No. 1874 D.D.D.1930. 500

Chart XXIII



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To accompany Geodetic Report Vol. V

TABLE 4.—*List of triangulation stations connected by spirit-levelling, season 1928-29 —(concld.).*

Name of station	Height above mean sea-level		Difference (Trian.—Levelling)	Remarks
	Spirit-levelling	Triangulation		
	feet	*feet*	*feet*	
Great Indus Series—(concld.).				
Farowāla T.S. Lat. 30° 49′ 53″·66 Long. 70 55 58·88	470·812	471	0	Ground floor mark-stone

TABLE 5.—*Lines Dehra-Kālsī-Mussoorie & Kālsī-Chakrātā-Mussoorie Comparisons of unadjusted orthometric heights as determined in different seasons.*

Sections	1903-04 (S.D.L.)	1905-06 (S.D.L.)	1908-09 (S.D.L.) Training school	1926 Training school	1926-27 (H.P.)	1928-29 (H.P.)
	feet	*feet*	*feet*	*feet*	*feet*	*feet*
(1) Dehra (B.M. 12/53J)-Rājpur (B.M. 21/53J) ...	..	+1636·547	...	...	+1636·582	...
(2) Rājpur (B.M. 21/53J)—Mussoorie (B.M.45/53J)	...	+2712·825	...	+2714·792	+2712·790	...
(3) Dehra-Mussoorie (1) + (2)	**+4349·757**	**+4349·372**	...	...	**+4349·372**	...
(4) Dehra (B.M. 12/53J)-Ambāri (B.M. 49/53F) ...	...	...	−624·296	...	...	−623·311
(5) Ambāri (B.M. 49/53F)-Mussoorie (B.M. 45/53J) via Bhadrāj ...	...	...	...	...	...	+4973·824
(6) Ambāri (B.M. 49/53 F)-Chakrātā (Serial 7) ...	...	...	...	...	...	+5166·923
(7) Chakrātā (Serial 7) -Mussoorie (B.M.45/53J)	...	...	...	...	..	−193·656
(8) Dehra-Mussoorie via Bhadrāj (4) + (5) ...	...	...	...	...	...	+4350·513
(9) Dehra-Mussoorie via Chakrātā (4) + (6) + (7)	...	...	...	...	...	+4349·956

CHAPTER VII

RESEARCH AND TECHNICAL NOTES

BY
DR. J. DE GRAAFF HUNTER, SC. D.
AND
CAPTAIN G. BOMFORD, R.E.

I. Dynamic and Orthometric heights

1. Summary of paras 1-3.—In the deduction of dynamic and orthometric heights from observed spirit-levelled heights, gravity is ordinarily assumed to have its normal formula value depending only on height and latitude. An example is given of a more rigorous deduction of dynamic and orthometric heights.

2. Dynamic height.—For the deduction of dynamic heights the Survey of India has adopted a series of equipotential surfaces of which those characterised by whole numbers of feet are each separated by one foot in a locality where gravity at a height of h feet is given by the formula

$$g_s = \gamma_s \,(1 - 2h/R)$$
$$= 978\cdot 00(1 + \cdot 005310 \sin^2 24° - 2h/R).$$

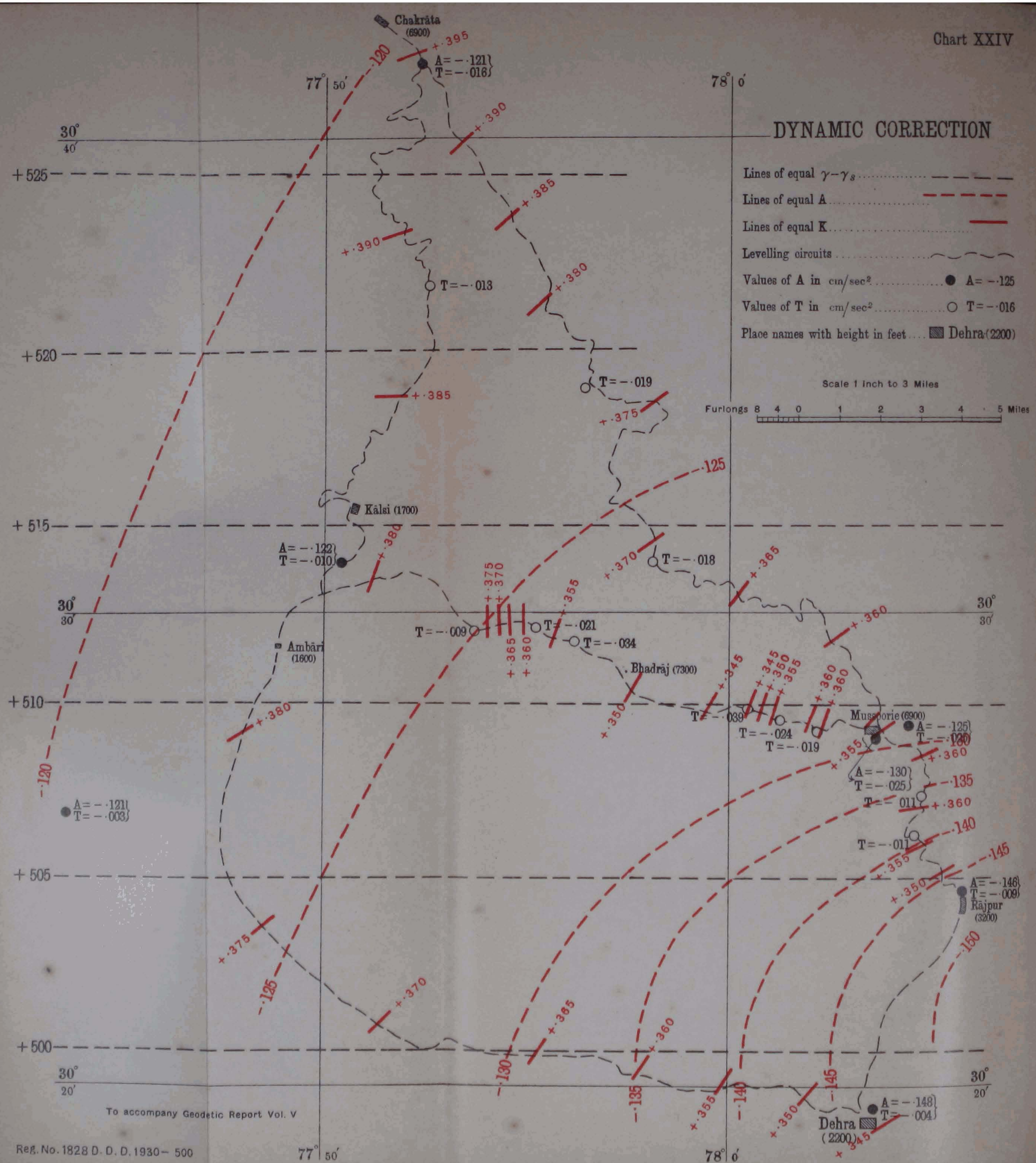
At the time when this system was adopted the above formula was considered to represent normal gravity in latitude 24°. More modern formulæ differ, but it still forms a perfectly reasonable basis for the computation of dynamic and orthometric heights. g_s is thus standard gravity at any height, and γ_s is standard gravity at sea-level. Then the separation between two consecutive standard equipotentials at any other place will be $1 - (g - g_s)/g_s$ feet, where g is the actual value of gravity at that place.

Let **M** be the height of a certain bench-mark as directly computed from spirit-levelling without dynamic correction, let **D** be its dynamic height, let **O** be its orthometric height, and let $\mathbf{M} \doteqdot \mathbf{D} \doteqdot \mathbf{O} \doteqdot H$, H being used for the height of the B.M. when the distinction between **M, D** and **O** is of no consequence.

Then $$\mathbf{D} = \mathbf{M} + \int_0^H (g - g_s)\, dh\,/g_s \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

g being the value of gravity at the place where each element dh is measured, and the integration being along the line of levelling.

Chart XXIV



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Now $g = \gamma (1 - 2h/R + 3h/4 \cdot 18\, R) + T + A$

where $\gamma^* = 978 \cdot 030\, (1 + \cdot 005302 \sin^2 \phi - \cdot 000007 \sin^2 2\, \phi)$,

T = Orographical correction (difference from plateau),

A = Bouguer anomaly.

Whence $(g - g_s) / g_s = (\gamma - \gamma_s + 3\gamma h / 4 \cdot 18\, R + T + A) / g_s$

$\doteqdot (\gamma - \gamma_s + 3\, \gamma_s h / 4 \cdot 18\, R + T + A) / \gamma_s \ldots$ (2)

with sufficient accuracy.

All the terms of this expression can be calculated at any point, except A, the anomaly. This is known if gravity has been observed at a number of points, and if the changes in A from point to point are sufficiently regular to justify interpolation. It is for this reason that the Bouguer formula has been used in preference to the Hayford; it is believed to be likely to give more accurate interpolation in small hilly areas, and has certainly done so in the area at present under consideration. The value of T does not vary greatly from place to place; it depends primarily on the roughness of country, and is not essentially different between hill and valley. If it is calculated at a number of points, it can be interpolated at intermediate points.

Then a chart can be drawn showing lines of equal $\gamma - \gamma_s$, lines of equal T, lines of equal A, and finally lines of equal K, where $K = 1000\ (\gamma - \gamma_s + T + A)/\gamma_s$.

Then we have $\mathbf{D} = \mathbf{M} + \int_0^H \left(\frac{K}{1000} + \frac{3 \cdot 42\, h}{100{,}000} \right) dh$, and $\mathbf{D}$ can easily be calculated with the help of the chart.

Chart XXIV shows lines of equal $\gamma - \gamma_s$, A and K in the area Dehra Dūn, Kālsī, Mussoorie and Chakrātā. Actual values of A and T are entered at places where pendulums have been swung, and orographical corrections computed, respectively. The small and regular variation of A is very notable in spite of the roughness of the country.

The result of applying the dynamic correction rigorously is to make an appreciable change in the dynamic height. (Between $0 \cdot 1$ and $0 \cdot 2$ in the case of the heights of Mussoorie or Chakrātā above Dehra). It might also be expected to improve the closing error of circuits a little, although T and A are the only terms in (2) which can contribute anything to this, since $\oint h.\ dh$ round a circuit is zero. Neglect of the rigorous correction can only cause serious closing error if the rise in a circuit occurs in an area with anomalies considerably different from those in the area in which the fall occurs, or if the rises and falls occur in areas with notably different orographical corrections. An example of the latter case is a circuit rising up a gently sloping plateau, falling abruptly over its edge, and returning to its starting point through flat plains. In the two circuits

* It is of no consequence that this formula differs from that used to define standard gravity. This formula is only a standard from which to measure the anomaly A.

shown in Chart XXIV, the closing errors are not much changed by the rigorous method of computing the dynamic correction. Thus the circuit Dehra-Kālsī-Bhadrāj-Mussoorie-Dehra, 66 miles, has the exceptionally large closing error of 0·658 feet with the usual correction, and the almost identical error of 0·662 feet with the rigorous. In the Kālsī-Chakrātā-Mussoorie-Bhadrāj-Kālsī circuit, 83 miles, the rigorous method improves the closing error from 0·057 to 0·014 feet, but in view of the inaccuracy of levelling with wooden staves in hill circuits, this improvement must be considered to be largely due to chance.

The subject is discussed further in para 10 of this chapter.

3. Orthometric height.— The orthometric height of a bench-mark is its vertical height above the standard sea-level equipotential beneath it. Since the separation between any two standard equipotentials is $1 - (g - g_s)/g_s$ feet (see para 2), we have

$$\mathbf{O} = \mathbf{D} - \int_0^H (g_h - g_s)\, dh \,/\, g_s \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where g_h is the value of gravity at a point h feet above sea-level on the vertical through the bench-mark. The integration is performed along the vertical.

As in (2), γ_s may be written for g_s in the denominator with sufficient accuracy, and

$$\mathbf{O} = \mathbf{D} - \frac{(\gamma - \gamma_s) H}{\gamma_s} - \frac{A H}{\gamma_s} - \frac{1}{\gamma_s}\int_0^H \textit{(vertical attraction of Topography)}\, dh \quad \ldots \quad (4)$$

In this equation the term $(\gamma - \gamma_s) H/\gamma_s$ is the usual orthometric correction*, the term $A H/\gamma_s$ presents no difficulty if A is known or can be interpolated†, but the term $I = \int_0^H \textit{(attraction of Topography)}\, dh$ requires investigation.

Following the Bouguer system, the topography may be considered to consist of a plateau, combined with hills and valleys. At the surface the attraction of a plateau is downwards, at sea-level it is upwards; the two cancel, and as regards the plateau the integral $\int_0^H g \,.\, dh$ is easily seen to be zero.

Then in evaluating I it is only necessary to measure the topography in terms of its height above or below the bench-mark.

Divide the topography into zones and compartments in the usual way, (see Chart XXV, figure 1). Then it is required to find $\int_0^H (\textit{attraction of } \mathrm{ABCD})\, dh$. Since only a low order of accuracy is

* Or, rather, it would be if γ and γ_s were calculated on the same formula.

† Its variation with height has to be ignored. If the anomaly is below sea-level and covers a large area, the variation with height is small.

Fig. 1 Orthometric Correction

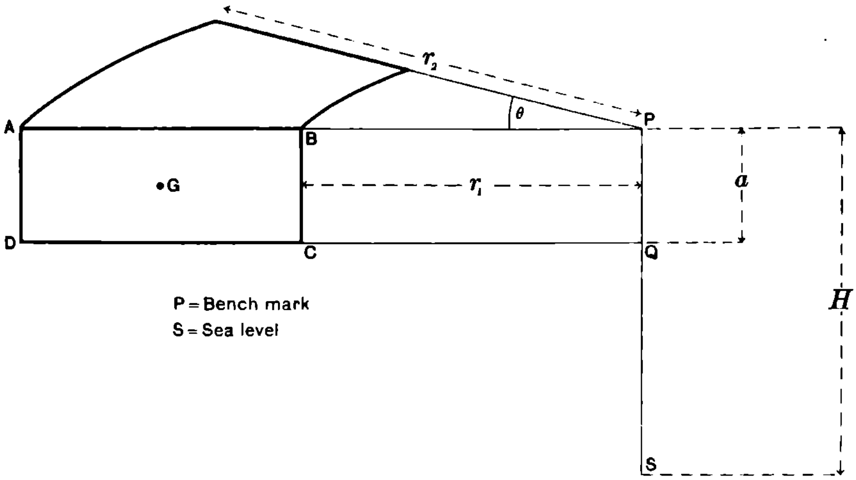
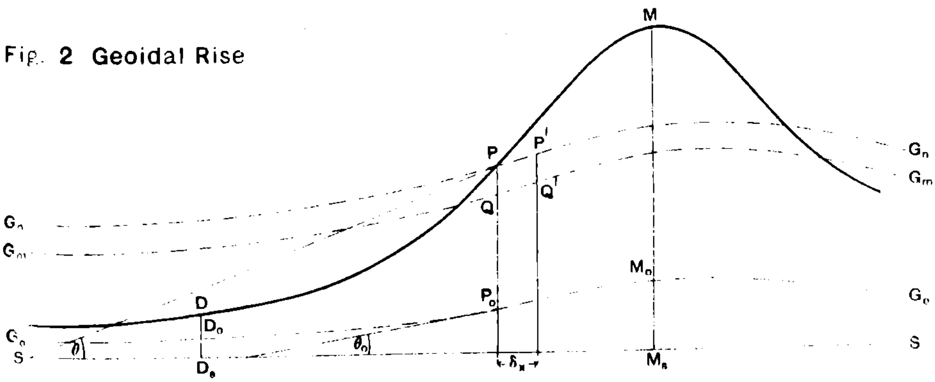


Fig. 2 Geoidal Rise



required, the mass of ABCD may be considered concentrated at its centre of gravity. Then for any compartment

$$I = -k \int_0^H \frac{\theta a \pi}{2\pi}\left(r_2^2 - r_1^2\right) \frac{\left(H - \frac{a}{2} - h\right)}{\left[\left(\frac{r_2+r_1}{2}\right)^2 + \left(H - \frac{a}{2} - h\right)^2\right]^{\frac{3}{2}}} dh.$$

$$= k\,\theta\,a\,(r_2^2 - r_1^2)\,\frac{(\cos\alpha - \cos\beta)}{(r_2+r_1)}.$$

where $\alpha = \tan^{-1}\dfrac{2H - a}{r_2 + r_1}$

$$\beta = \tan^{-1}\frac{a}{r_2 + r_1}$$

To eliminate k, we have g = attraction of the Earth

$$= \frac{4}{3}\pi k . \frac{R^3}{R^2} 2 \cdot 09,$$

$2 \cdot 09$ being the ratio of the earth's mean density to mean surface density, and R being earth's mean radius.

whence $$I/g_s = \frac{3\theta a\,(r_2^2 - r_1^2)}{4\pi\,R\,2\cdot 09} \times \frac{(\cos\alpha - \cos\beta)}{(r_2 + r_1)}$$

$$= \frac{\theta\,a}{2\pi}\,\frac{1}{29\cdot 2.\;10^6}(r_2 - r_1)(\cos\alpha - \cos\beta)\text{ feet} \ldots (5)$$

where a is the height of the compartment *below* the station, and r_2 and r_1 are measured in feet.

Equation (5) has to be summed for all necessary zones and compartments.

The full computation has been made in the case of two bench-marks at Dehra Dūn and Mussoorie, as follows:—

	Dehra Dūn B.M. 10/53J	Mussoorie B.M. 51/53J
Height	2234 *feet*	6740 *feet*
$(\gamma - \gamma_s)\ H/\gamma_s$	+ 1·108 *feet*	+ 3·340 *feet*
A	− 0·123 *cm/sec²*	− 0·145 *cm/sec²*
AH/γ_s	− 0·281 *feet*	− 0·998 *feet*
I/γ_s	− 0·01 *feet*	− 0·22 *feet*
O − D	− 0·84 *feet*	− 2·56 *feet*

The height of Mussoorie above Dehra as arrived at by different methods may now be summarised as follows:—

Observed difference, via Rājpur (1927)	4505·966	feet	
Dynamic difference, usual method	4508·140	„	
Dynamic difference, rigorous method	4508·261	„	
Orthometric difference, usual method	4505·86	„	difference
Orthometric difference, rigorous method	4506·54	„	0·68.

According to the Dehra-Kālsī-Mussoorie observations these figures should be between 0·6 and 0·7 feet greater. The Dehra-Rājpur-Mussoorie levelling of 1905-07 agrees with the 1927 values within ·010.

II. Height correction to Deviation of the Vertical

4. Summary of paras 4-6.—It is customary to apply to latitude observations a small correction of $0 \cdot 000053\ H \sin 2\phi$ on account of the lack of parallelism between the ground level and sea-level equipotential surfaces at points on the same vertical. In hilly country this lack of parallelism may amount to some seconds, i.e. to several times the formula value, and may occur in the prime vertical as well as in the meridian. Some examples are given of a rigorous reduction to sea-level, and of the resulting change in the geoidal height of a station, as deduced by triangulation.

5. Calculation of the correction.—The intensity and direction of gravity at any point is given by the vectorial sum of:—

(a) The attraction of the spheroid, corrected for height, viz, $\gamma_0 - 2gH/R$.

(b) The attraction of a plateau of the same height as the station viz, $3gH/4 \cdot 18R$.

(c) The attraction of the hills and valleys in the plateau.

(d) The attraction of the anomalies.

The deflection is given by the ratio which the components of the above attractions, which lie tangential to the spheroid, bear to the normal components. Comparing the deflections at ground level and sea-level vertically beneath, it is clear that the vertical components are sensibly the same (within $0 \cdot 1\%$): the change in the horizontal component of the attraction of the spheroid is allowed for by the usual height correction: the horizontal attraction of the plateau is zero in both cases: the attraction of the anomalies may be different, but in as much as Bouguer anomalies are primarily caused by more or less deep-seated lack of compensation, it is not unreasonable to assume the change in the horizontal component to be small and to neglect it: as indeed is inevitable. It remains to calculate the change in the horizontal attraction of the topography. In rough country at a considerable height above sea-level, this may be considerable: for it is clear that a surface excess or defect may cause appreciable deviation of the vertical at a near-by station at its own level, but much less at a point some thousands of feet below.

Let the country surrounding a station be divided up into zones and compartments in the usual way, so that 100 feet of height in each compartment corresponds to a deviation of the vertical of $0''\cdot01$ at the station (see Hayford, "Figure of the Earth and Isostasy"). Let the total horizontal attraction at the station of the topography in any one zone be F, and let the attraction of the same topography at sea-level below the station be F_0. Then the ratio F_0/F depends on the bounding radii of the zone, and on the height of the station, and is easily calculable. It is clear that the resulting deflections bear the same ratio, with the result that:—

$$\phi - \phi_0 = \eta - \eta_0 = \Sigma \eta_T (1 - F_0/F) \quad \ldots \quad \ldots \quad (6)$$

where ϕ = observed latitude $- \cdot 000053\, H \sin 2\phi$,

ϕ_0 = latitude fully reduced to sea-level,

η = observed deflection $- \cdot 000053\, H \sin 2\phi$,

η_0 = deflection at sea-level,

η_T = the estimated topographical deflection,

and $(1 - F_0/F)$ is given in Table 2.

The summation is taken over all the usual topographical zones. Northerly deflections are reckoned negative.

And in the prime vertical:—

$$(\lambda - \lambda_0) \cos\phi = \xi - \xi_0 = \Sigma \xi_T (1 - F_0/F) \quad \ldots \quad \ldots \quad (6a)$$

where λ = observed longitude,

λ_0 = longitude reduced to sea-level,

ξ = observed deflection,

ξ_0 = deflection at sea-level,

ξ_T = estimated topo deflection.

Easterly deflections are reckoned negative.

Topographical deflections may be estimated with or without isostatic compensation. The differential effect is only considerable in the case of near zones, where the Hayford compensation factor is nearly unity. Since it can hardly be believed that Hayford compensation follows the surface features in minute detail, it is probably best to ignore it for the purpose of this reduction, but the inaccuracy of the final result cannot be considered to be much less than the difference between the results of computation with and without compensation.

6. Application to Dehra-Mussoorie.—Between Dehra Dūn and Mussoorie are a number of deflection stations, (see Chart XXIV), which have been utilised to deduce the rise of the geoid between these two places. They have now been rigorously reduced to sea-level (see Table 1), and the geoidal rise recomputed.

TABLE 1.

Station	Latitude			Longitude			Height	Deflection at surface $-0\cdot000053 \times H \sin 2\phi$	Deflection at sea-level
	°	′	″	°	′	″	*feet*	″	″
Dehra Dūn	30	19	29	78	3	22	2240	36·9 N	36·8 N
III	30	21	47	78	4	07	2660	41·0 N	40·9 N*
IV	30	22	09	78	4	31	2780	42·2 N	42·0 N*
V	30	22	52	78	5	21	2980	44·4 N	43·9 N*
VI	30	23	31	78	6	02	3050	45·9 N	44·9 N*
Rājpur	30	23	57	78	6	00	3500	47·7 N	46·0 N
Spur Point	30	24	38	78	5	36	3850	53·2 N	48·9 N
Jharipāni	30	25	10	78	5	21	5150	52·5 N	47·2 N
Mussoorie	30	27	41	78	4	17	6937	36·8 N	35·1 N

It will be noticed that the deflection at Jharīpāni is changed by over 5″. Spur Point and this station are unusual stations situated on the side of the hill, but even at Mussoorie on top of the hill, the correction is as much as 1″·7. Using the uncorrected deflections the geoidal rise may be computed to be 10·56 feet. Using the sea-level values it is 10·11, a difference of 0·45 feet.

In Professional Paper 14, pages 22 and 28, it is shown that if the geoidal rise be taken as 10·2 feet †, the triangulated height of Mussoorie above Dehra is 1·94 feet greater than that derived from spirit-levelling computed with the usual orthometric correction. Hence from the table at the end of para 3, it is seen that the triangulated height of Mussoorie above Dehra is:—‡

4507·44 feet, if the geoidal rise is computed with usual values of the deflections.

4507·89 feet, if the geoidal rise is computed with sea-level values of deflections.

It will be noticed that the disagreement between the spirit-levelled and triangulated heights is lessened to the extent of 0·68 feet by the rigorous application of the orthometric correction (see end of para 3), but is increased by 0·45 feet by the reduction of deflection observations to sea-level. (See above).

* $\Sigma\eta_T\,(1 - F_0/F)$ estimated roughly by comparsion between Dehra Dūn and Rājpur.

† A value arrived at before observations had been made at Jharipāni and Spur Point.

‡ These height differences refer to B. Ms. 10 & 51/53 J. The latter was not a triangulation station, but has been connected to the station by a short line of spirit-levelling.

III. Comparison of Spirit-Levelled and Triangulated Heights.

7. Summary of paras 7-10.—The rigorous application of the orthometric correction to levelling, and the rigorous reduction to sea-level of deflections used for computing the geoidal rise, are shown to make essentially equal changes in the geoidal height of a station as deduced by spirit-levelling on the one hand, and by triangulation on the other. The necessity for these rigorous corrections is discussed, and it is concluded that if both be omitted little harm will result, whereas their inclusion involves an almost impossible amount of labour.

8. The two corrections are identical.—In para 5 the change in the geoidal rise which results from reducing all observed deflections to sea-level, has been computed by considering in detail the attraction of the topography, both at every station, and at sea-level below every station. A more general expression can be obtained as follows :—

In Chart XXV, figure 2, D is one station (Dehra Dūn) and M is another (Mussoorie). P is any intermediate station (Jharīpāni), S is the spheroid, G_0 the geoid; G_m and G_n are other equipotentials. θ is the inclination to the spheroid of the ground level equipotential at P, and θ_0 is the inclination of the geoid below P.

If R (i. e. $M_0 M_s - D_0 D_s$) be the geoidal rise between Dehra and Mussooorie, and if R' be that deduced if ground level deflections are used (i. e. if $G_0 G_0$ and $G_n G_n$ are assumed parallel), we have:—

$$R' - R = \int_D^M \left(\theta - \theta_0\right) dx \qquad \ldots \qquad \ldots \qquad \ldots (7)$$

x being the horizontal component of distance measured along the line.

Now since the intensity of gravity is inversely proportional to the spacing of the equipotentials, we have at P:—

$$\left(P'Q' - PQ\right)/PQ = \frac{dg}{dx} \cdot \delta x \;/ g$$

$$\left(P'Q' - PQ\right)/\delta x . PQ = \frac{dg}{dx}/g$$

$$\text{and } \theta - \theta_0 = \int_{P_0}^{P} \frac{P'Q' - PQ}{\delta x . PQ} dh = \frac{1}{g}\int \frac{dg}{dx} . dh$$

$$\text{and from (7), } R' - R = \frac{1}{g}\int_D^M \int_{P_0}^{P} \frac{dg}{dx} . dh . dx ,$$

the integrals being taken over the area $D_0 D$ P M $M_0 P_0$

$$= \frac{1}{g}\int_0^H \Delta g.\, dh \qquad \dots \qquad \dots \qquad \dots \quad (8)$$

where Δg is the difference between gravity at any point on MM_0, and its value at the same height on DD_0 or DPM.

Now from (1) and (3) we see that the orthometric correction to the line D_0DPMM_0 is given by

$$O - M = \int_0^H (g - g_s)\, dh / g_s - \int_0^H (g - g_s)\, dh / g_s,$$

the first integral being taken along the line of levelling, and the second along MM_0.

$$= \frac{1}{g}\int_0^H \Delta g.\, dh$$

as in (8), since the distinction between g and g_s is immaterial in the denominator.

It is thus proved that the orthometric correction is equal to the difference between the geoidal rise as computed correctly and as computed with surface values of the deflection. And it is clear that the error in the orthometric correction due to the use of formula values of gravity, is equal to the error in geoidal rise due to the use of formula corrections to sea-level.

9. The height of Mussoorie above Dehra Dun.—In para 3 the application of the rigorous orthometric correction changed the spirit-levelled height by 0·68 feet; in para 6 the reduction of deflection to sea-level has changed the triangulated height by 0·45 feet. It is shown in para 8 that these two figures should be identical. The size of the discrepancy is not altogether surprising. The second figure, especially, contains possible sources of error. It has been derived by integrating up the value of $\theta - \theta_0$ at the few latitude stations between Dehra and Mussoorie. Although these stations are reasonably typical, this integration cannot be expected to give high class accuracy, for the value of $\theta - \theta_0$ depends especially on the near topography, which varies rapidly from place to place. In particular, it is to be expected that at places between Jharīpāni and Mussoorie $\theta - \theta_0$ will be greater than has been derived by interpolation between these two places: for the ground is very steep, all the way up to Mussoorie. Of the two figures 0·68 is probably the more correct.

The height of Mussoorie (B.M. 51) above Dehra Dūn (B.M 10) may be summarised thus :—

By spirit-levelling, fully corrected	4506·54 ft.
By triangulation, fully corrected	4507·89 ft.
Triangulation *minus* levelling	1·35 ft.

It seems impossible to explain this discrepancy on any ground other than observational error, probably in the levelling. In Professional Paper 14 it has been shown that it is exceedingly unlikely to be due to refraction or other errors in the angles of the triangulation. In Professional Paper 22 it has been shown that it is unlikely to be due to refraction error in the levelling, but it is possible that it is due to errors in staff length (see Chapter VI of this report, para 6).

It may be remembered that levelling via Kālsī lessens this discrepancy by 0·6 or 0·7 feet (see para 3). It is hoped that relevelling with invar staves will settle the problem. A further possible source of error is in the horizontal distance between the triangulated stations, but this cannot be now verified, on account of the destruction of one of them.

10. Conclusions.—In hilly country the rigorous application of the dynamic and orthometric corrections is an immense labour. In flat country it is of no consequence. In para 2 it has been shown that it has no great effect on the closure of circuits, and in para 8 it is shown to have no effect on comparison with triangulated height, provided the deflections from which the geoidal rise is computed are reduced to sea-level by the formula value only. It is true that the use of formula values of gravity results in heights being expressed in an unknown unit above an unknown datum, but no discrepancies arise to cause trouble, the error is not great (0·7 feet in 7000 at Mussoorie), and it does not change abruptly between one bench-mark and another near one. It may be concluded that the labour required to express results in true units above the geoid is not justifiable.

TABLE 2.— $1 - F_0/F$.

Zone number, inner, and outer radius (in miles)

Height of station	38 ·0000 ·0049	37 ·0049 ·0070	36 ·0070 ·0099	35 ·0099 ·0142	34 ·0142 ·0202	33 ·0202 ·0288	32 ·0288 ·0410	31 ·0410 ·0585	30 ·0585 ·0834	29 ·0834 ·1190	28 ·1190 ·1696	27 ·1696 ·2419	26 ·2419 ·3449	25 ·3449 ·4918	24 ·4918 ·7013	23 ·7013 1·0000	22 1·0000 1·426	21 1·426 2·033	20 2·033 2·899	19 2·899 4·134	18 4·134 5·895	17 5·895 8·406	16 8·406 11·987	15 11·987 17·09	14 17·09 24·37	13 24·37 34·75	12 34·75 49·56
feet																											
0	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
100	·99	·97	·93	·84	·71	·52	·35	·20	·11	·06	·03	·02	·01	·01	·01	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
200	1·00	1·00	·99	·97	·93	·84	·70	·50	·34	·20	·10	·05	·03	·01	·01	·01	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
300	1·00	1·00	1·00	·99	·98	·94	·86	·72	·55	·35	·20	·11	·06	·03	·02	·02	·01	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
400	1·00	1·00	1·00	1·00	·99	·96	·93	·83	·69	·49	·30	·18	·10	·05	·03	·02	·01	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
500	1·00	1·00	1·00	1·00	·99	·98	·97	·89	·78	·62	·43	·26	·15	·08	·04	·03	·01	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
750	1·00	1·00	1·00	1·00	1·00	1·00	·98	·96	·91	·80	·67	·46	·29	·16	·09	·05	·03	·01	·01	·01	·00	·00	·00	·00	·00	·00	·00
1000	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·96	·90	·78	·62	·42	·25	·15	·07	·04	·02	·02	·01	·00	·00	·00	·00	·00	·00	·00
1500	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·96	·91	·80	·65	·45	·28	·16	·08	·04	·03	·02	·01	·01	·00	·00	·00	·00	·00
2000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·98	·96	·90	·78	·60	·40	·25	·13	·07	·04	·03	·01	·01	·01	·00	·00	·00	·00
2500	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·97	·93	·84	·72	·53	·34	·19	·11	·05	·03	·02	·01	·01	·00	·00	·00	·00
3000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·96	·90	·79	·63	·44	·26	·15	·07	·04	·02	·02	·01	·00	·00	·00	·00
3500	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·97	·93	·84	·71	·52	·33	·19	·10	·05	·03	·02	·01	·00	·00	·00	·00
4000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·96	·89	·77	·59	·40	·24	·13	·07	·04	·02	·01	·00	·00	·00	·00
4500	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·98	·97	·92	·81	·65	·46	·29	·16	·08	·05	·03	·01	·00	·00	·00	·00
5000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·97	·94	·85	·71	·52	·34	·20	·10	·06	·03	·02	·01	·01	·00	·00
6000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·98	·96	·90	·79	·62	·43	·26	·14	·08	·04	·03	·01	·01	·01	·00
7000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·98	·97	·93	·84	·70	·51	·32	·19	·10	·05	·03	·02	·01	·01	·00
8000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·95	·88	·76	·58	·39	·24	·13	·07	·04	·02	·02	·01	·01
9000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·96	·91	·80	·65	·45	·28	·16	·09	·05	·02	·02	·01	·01
10000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·97	·94	·84	·70	·51	·33	·19	·11	·06	·03	·02	·01	·01
12000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·96	·88	·78	·61	·42	·26	·14	·08	·04	·02	·01	·01
15000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	·99	·98	·94	·86	·73	·54	·35	·21	·12	·06	·03	·02	·01

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SYNOPSIS

Part I—Numerical Data

Part II—Geodetic Works of Reference

* Part III—Historical and General Reports

* Part IV—Catalogues and Instructions

* Part V—Miscellaneous Papers

*** 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° × 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: Sheet	Pamphlet: Distinctive name of sheet	Latitude	Longitude	Published in	Price
		° °	° °		
34	(Quetta) ...	28–32	64–68	1916	Rs. 2-0-0
35	(Karāchi) ...	24–28	64–68	1911	Rs. 2-0-0
38	(Kābul) ..	32–36	68–72	1912	Rs. 2-0-0
39	(Multān) ...	28–32	68–72	1913	Rs. 2-0-0
	Addendum to 39 ...	...	...	1916	Rs. 2-0-0
40	(Hyderābād, Sind) ...	24–28	68–72	1911	Rs. 2-0-0
41	(Rājkot) ...	20–24	68–72	1913	Rs. 2-0-0
43	(Srīnagar) ...	32–36	72–76	1913	Rs. 2-0-0
	Addendum to 43 ...	...	..	1915	Rs. 2-0-0
44	(Lahore) ...	28–32	72–76	1926	Rs. 3-0-0
45	(Ajmer) ...	24–28	72–76	1911	Rs. 2-0-0
46	(Baroda) ...	20–24	72–76	1912	Rs. 2-0-0
47	(Bombay) ...	16–20	72–76	1912	Rs. 2-0-0
	Addendum to 47, Island of Bombay ...	...	...	1915	Re. 1-0-0
48	(Goa) ...	12–16	72–76	1912	Rs. 2-0-0
49	(Calicut) ...	8–12	72–76	1911	Re. 1-0-0
52	(Leh) ..	32–36	76–80	1912	Re. 1-0-0
53	(Delhi) ...	28–32	76–80	1920 (reprinted 1929)	Rs. 3-0-0
54	(Agra) ...	24-28	76–80	1921	Rs. 2-0-0

Levelling Pamphlets—(*Continued*).

Sheet	Pamphlet: Distinctive name of sheet	Latitude	Longitude	Published in	Price
		°	°		
55	(Nāgpur) ...	20–24	76–80	1912	Rs. 2-0-0
56	(Hyderābād, Deccan) ...	16-20	76–80	1912	Rs. 2-0-0
	Addendum to 56 ...	...	...	1919	Re. 1-0-0
57	(Mysore) ...	12–16	76–80	1919	Rs. 2-0-0
58	(Ootacamund) ..	8–12	76–80	1914	Rs. 2-0-0
62	(Mānasarowar) ...	28–32	80–84	1922	Re. 1-0-0
63	(Allahābād) ...	24–28	80–84	1923	Rs. 2-0-0
64	(Raipur) ...	20–24	80-84	1912	Rs. 2-0-0
65	(Vizagapatam) ...	16-20	80-84	1913	Rs. 2-0-0
66	(Madras) ...	12-16	80-84	1912	Rs. 2-0-0
72	(Kātmāndu) ...	24–28	84–88	1912	Rs. 2-0-0
	Addendum to 72 ...	...	...	1919	Rs. 2-0-0
73	(Cuttack) ...	20–24	84–88	1913	Rs. 2-0-0
	Addendum to 73 ...	...	...	1920	Rs. 2-0-0
74	(Purī) ..	16–20	84–88	1913	Rs 2-0-0
78	(Darjeeling) ...	24–28	88-92	1923	Rs. 2-0-0
79	(Calcutta) ...	20–24	88–92	1924	Rs. 2-0-0
83	(Dibrugarh) ...	24–28	92–96	1912	Rs. 2-0-0
84	(Akyab) ...	20-24	92-96	1918	Rs. 2-0-0
85	(Prome) ...	16-20	92–96	1917	Rs. 2-0-0
92	(Bhamo) ...	24–28	96-100	1918	Rs. 2-0-0
93	(Mandalay) ...	20–24	96-100	1917	Rs. 2-0-0
94	(Rangoon) } ...	16-20	96-100	1916	Rs. 2-0-0
95	(Mergui) }	12-16	96-100		

(b) Levelling of Precision in Mesopotamia—

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

(ii) Levelling of Secondary Precision—

Descriptions and heights of bench-marks 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	,,	,,

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 Alī via Umarkot and Dādāh) ...	40 C, D, G & H	,,	,,
10	52J (Mīrpur Khās to Tando Ghulām Alī via Dīgrī) ...	40 G	,,	,,
11	52K (Dīgrī to Dādāh) ...	40 G & H	,,	,,
12	70J (Barākar to Hazāribāgh Road)	73 I and 72 H & L	,,	As. 12
13	74C (Howrah to Uttarpāra) 74D (Baidyabāti to Sheorāphūli) 74E (Bāndel Church to Bāndel Ry. Stn.) 74F (B.M. 251(*118*)/79A to Pandua Ry. Stn.)	79 A & B	,,	As. 8
14	74G (B.M. 126/73M to Saktigarh Ry. Stn.) 74H (B.M. 116/73M to Burdwān Ry. Stn.) 70E (B.M. 85/73M to Mānkar Ry. Stn.) 70F (B.M. 76/73M to Pānagar Ry. Stn.) 70G (B.M. 58/73M to Durgāpur Ry. Stn.) 70H (B.M. 28/73M to Rānīganj Ry. Stn.) 70 I (B.M. 15/73M to Asansol, Kālīpāhari & Churulia) 70M (Khāna Ry. Stn. to Galsi Ry. Stn.)	73 I & M	,,	As. 12
15	77Q (Calcutta to Nārāyanpur) 77R (Nārāyanpur to Nārāyanpur)	79 B	,,	Re. 1
16	87A (Moulmein to Paan) 87B (Moulmein to Wekali) 87C (Babukon to Kawmyatkyi) 87D (Nyaungbinzeik to Natchaung)	94 H & L and 95 E & I	,,	As. 12

Levelling Pamphlets—(*Continued*).

Serial No.	Line number	Situated in degree sheets	Published in	Price
17	88B (Kyauktaga to Myitkyo) 88C (Dalanun to 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 (Nira 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 & 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 Dakhinesar) ...	79 B	"	"

Levelling Pamphlets.—(*Concluded*).

Serial No.	Line number	Situated in degree sheets	Published in	Price
36	70K (Allāhābād to Barākar) ...	63 G, K & O, 72 C, G, K&L and 73 I	,,	As. 14
37	70L (Mughal Sarai to Hazāribāgh Road) ...	63 O & P and 72 D & H	,,	As. 10

Tide-Tables—

Since 1881 Tidal predictions based on the observations of the Survey of India have been published annually by the India Office, London, up till the year 1922. From 1923 onwards the prediction and publication have been undertaken at Dehra Dūn by the Survey of India. The tables give the times and heights of high- and low-water for every day in the year for 37 ports, and are published early in the previous year. They are published as follows :—

(i) A single volume styled "**The Major Series**" comprising Tide-Tables for the following ports:—

Suez, Aden, Bushire, Karāchi, Okha Point & Bet Harbour, Bhāvnagar, Bombay, Cochin, Tuticorin, Pāmban Pass, Colombo, Madras, Vizagapatam, Dublat, Diamond Harbour, Kidderpore, Chittagong, Elephant Point and Rangoon. *Price Rs. 8.*

(ii) **Combined Pamphlets** as below :—

(*a*) Okha Point and Bet Harbour (Mouth of the Gulf of Cutch)
Porbandar
Port Albert Victor (Kāthiāwār)
Bhāvnagar *Price Rs. 1-8.*

(*b*) Marmagao
Kārwār *Price Rs. 1-2*

(*c*) Dublat (Sāgar Island)
Diamond Harbour
Kidderpore (Calcutta) — Hooghly River *Price Rs. 1-8*

(*d*) Amherst
Moulmein — Moulmein River *Price Rs. 1-2.*

(*e*) Tuticorin
Pāmban Pass (Island of Rāmeswaram) *Price Rs. 1-2.*

(*f*) Colombo
Galle
Trincomalee — Ceylon *Price Rs. 1-8.*

(*g*) Diamond Island
Bassein — Bassein River *Price Rs. 1-2.*

(*h*) Elephant Point
Rangoon — Rangoon River *Price Rs. 1-2.*

Tide-Tables—(*Continued*).

(iii) **Separate pamphlets** for each of the following ports:— Suez, Aden, Basrah, Bushire, Karāchi, Bombay, Beypore, Cochin, Negapatam, Madras, Cocanāda, Vizagapatam, False Point, Chittagong, Akyab, Mergui, and Port Blair. *Price of each pamphlet is As. 12.*

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, R.F.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 I_B, 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 S and **A** for determining the Expansion of **A**.
- Appendix No. 7. Final determination of the Differences in Length between the 10-feet Standards I_B, 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 1855.

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 N.W. 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, N.W 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'. Pendulum at the Ordnance Survey Office, Southampton.

Appendix No. **2** On the Relation between the Indian Pendulum Operations, and those which have been conducted elsewheres

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 an 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 Dun, 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. (1851-67 and 1869-70, out of print). *Price Rs. 3.*

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 Inida**".

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 Somāliand 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 Mīri 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 Exploratoins, 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.*

(*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.*

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.** —	834
2.—**Circular Orders (Administrative).** —	420
3.—**Circular Orders (Professional).**—	196
4.—**Departmental Orders** (appointments, promotions, transfers, etc.)	

These are numbered serially and had reached the above numbers by September 1928. *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 Hand-books. 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.
   - Ditto ditto 1904-1908.—Calcutta, 1909. (Out of print).
   - Ditto ditto 1909-1913.—Calcutta, 1915.
   - Ditto ditto 1914-1918.—Calcutta, 1920.
2. *Circular Orders (Administrative) 1878-1903.—Calcutta, 1904.
   - Ditto ditto 1904-1908.—Calcutta, 1909.
   - Ditto ditto 1909-1913.—Calcutta, 1915.
   - Ditto ditto 1914-1918.—Calcutta, 1920.
   - Ditto ditto 1919-1924.—Dehra Dūn, 1926.

Departmental Orders.—(*Concluded*)

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. Corrected. to 31st March 1928, Calcutta, 1928. *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 the Bombay Presidency, Calcutta, 1913. *Price As. 4.*
3. **Catalogue of Maps of Burma.** Calcutta 1925. *Price As. 8.*
4. **Catalogue** of Maps of Cantonments and Military stations. Dehra Dūn, 1927. *Price As. 8.*
5. **Catalogue** of Books in the headquarters Library, Calcutta, 1901. (Out of print).
6. **Catalogue** of Scientific Books and Subjects in the Library of the Trigonometrical Survey Office. Dehra Dūn, 1908. *Price Re. 1.*
7. Classified **Catalogue** of the Trigonometrical Survey Library. Dehra Dūn, 1921. *Gratis.*
8. **Green Lists**—Part I—List of Officers in the Survey of India (annually to date 1st January), Calcutta. *Price Rs. 3-4.*
   Part II—History of Services of Officers in the Survey of India (annually to date 1st July), Calcutta. *Price Rs. 1-8.*
9. **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. 6-12.*
   Part II—Circles and parties (published annually to date 1st January). Calcutta. *Price Rs. 5.*
10. **List of the publications of the Survey of India** (published annually) Dehra Dūn. *Gratis.*
11. **Price List of Mathematical Instrument Office.** Corrected up to 1st September 1927, Calcutta, 1928. *Gratis.*

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—

* For Departmental use only.

Tables and Star Charts.—(*Continued*).

Part I—Graticules of Maps, (reprinted). Dehra Dūn, 1926. *Price Re. 1.*

Part II—Mathematical Tables, (reprinted with additions). Dehra Dūn, 1924. *Price Rs. 2.*

Part III—Topographical Survey Tables, (reprinted with additions). Dehra Dūn, 1928. *Price Rs. 3.*

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. * Ditto ditto 10 feet. Calcutta, 1915.

11. * Ditto ditto 8 feet. Ditto.

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.

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).

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.-Colonel R. Smyth. Third Edition, revised and enlarged. Calcutta, 1875. (Out of print).

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

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* **For Departmental use only.**

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 V—The Tides. Third Edition, revised, Dehra Dūn 1926. *Price Rs. 2.*

Part VI—Levelling. Third 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 1923. *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.*

Chapter VII—Forest Surveys and Rectangulation (old Chapter IX) revised, 1925. *Price As. 8.*

„ VIII—Surveys in war and Trans-frontier Reconnaissance (old Chapters VII and VIII). *Under preparation.*

„ IX—Geographical Maps (old Chapter XI). Second Edition, 1926. *Price As. 8.*

„ X—Map Reproduction. Second Edition, 1919. *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.*

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).

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* For Departmental use only.

Notes and Instructions.—(*Continued*).

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 account 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.

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

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

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Unclassified Papers.—(*Continued*).

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

4. Routes in the Western-Himālaya, Kashmīr, etc. with which are included Montgomerie's Routes. Volume I. Pūnch, Kashmīr and Ladākh, by Major Mason, M.C., R.E., First Edition, Dehra Dūn, 1923. *Price Rs. 6.*

Exploration.

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

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

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

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

Special Reports.

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

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

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

4. *The Total Solar Eclipse, 22nd January, 1898. Dehra Dūn, 1898.

(1) Report on the observations at Dumraon.
(2) Report on the observations at Pulgaon.
(3) Report on the observations at Sahdol.

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

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

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

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

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

Geodesy.

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

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* For Departmental use only.

Unclassified Papers.—(*Concluded*).

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

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

Projections.

1. On the projection used for the General Maps of India. Dehra Dūn, 1903. (Out of print).

2. *On the deformation resulting from the method of constructing the International Atlas of the World on the scale of one to one million, by Ch. Lallemand. Translated by J. Eccles, M.A., together with tables for the projection of 1/M Maps on the International system. Dehra Dūn, 1912. (Out of print).

Mapping.

1. *A Note on the different methods by which hills can be represented upon maps, by Colonel S. G. Burrard, C.S.I., R.E., F.R.S., Surveyor General of India. Simla, 1912.

2. *A Note on the representation of hills, by Major C. L. Robertson, C.M.G., R.E. Dehra Dūn, 1912.

3. *A Note on the representation of hills on the Maps of India, by Major F. W. Pirrie, I.A. Dehra Dūn, 1912.

4. *A consideration of the Contour intervals, and Colour Scales, best suited to Indian 1/M maps, by Captain M.O'C. Tandy, R.E. Calcutta, 1913. (Out of print).

Professional Papers.

No. 1—**Projection**—On the Projection for a Map of India, and adjacent Countries, on the scale of 1: 1,000,000, by Colonel St. G. C. Gore, R.E. Second Edition. Dehra Dūn, 1903. *Price Re. 1.*

No. 2 ***Base Lines**—Method of measuring Geodetic Bases by means of Metallic Wires, by M. Jäderin. (Translated from Memoires Présentés par Divers. Savants à l' Académie des Sciences de l' Institute de France). Dehra Dūn, 1899. (Out of print).

No. 3—**Base Lines**—Method of measuring Geodetic Bases by means of Colby's Compensated Bars, compiled by Lieut. H. McC. Cowie, R.E. Dehra Dūn, 1900. (Out of print).

No. 4—**Spirit levels**—Notes on the Calibration of Levels, by Lieut. E. A. Tandy, R.E. Dehra Dūn, 1900. (Out of print).

No. 5—**Geodesy**—The Attraction of the Himālaya Mountains upon the Plumb-Line in India, *considerations of recent data*, by Major S. G. Burrard, R.E. Second Edition. Dehra Dūn, 1901. *Price Rs. 2.*

No. 6—**Base Lines**—Account of a Determination of the Coefficients of Expansion of the Wires of the Jäderin Base Line Apparatus, by Captain G. P. Lenox-Conyngham, R.E. Dehra Dūn, 1902. (Out of print).

* For Departmental use only.

Professional Papers.—(*Continued*).

No. 7—***Miscellaneous.** Calcutta, 1903.

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1. *India's Contribution to Geodesy, by General J. T. Walker, R.E., C.B., F.R.S., LL.D. (Philosophical Transactions, Royal Society, Series A, Volume 186, 1895).

2. *On the Intensity and Direction of the Force of Gravity in India, by Lt.-Colonel S. G. Burrard, R.E, F.R.S. (Philosophical Transactions, Royal Society, Series A, Volume 205, pages 289-318, 1905).

3. †A climb on Kolahoi, by Lieut. Kenneth Mason, R.E. (Royal Engineers Journal, November 1910).

4. *On the effect of the Gangetic Alluvium on the Plumb-line in Northern India, by R. D. Oldham, F.R.S (Proceedings of the Royal Society, Series A, Volume 90, pages 32-40, 1914).

5. *On the origin of the Indo-Gangetic trough, commonly called the Himālayan Foredeep, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Proceedings of the Royal Society, Series A, Volume 91, pages 220-238, 1915).

6. §Three comprehensive articles on "Comparators for the Indian Government" from a report by Major H. McC. Cowie, R.E. (Engineering, Aug. 20, Aug. 27, Sept. 3, 1915).

7. ||Identification of Peaks in the Himālaya with notes, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Geographical Journal, September 1918).

8. ||Geological interpretations of Geodetic Results, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Geographical Journal, October 1918).

9. ||War Surveys in Mesopotamia, by Colonel F. W. Pirrie, C.M.G. I.A. (Geographical Journal, December 1918).

10. ||Air Photography in Archæology, by Lt.-Colonel G. A. Beazeley, D.S.O., R.E. (Geographical Journal, May 1919).

11. ||Mapping from Air Photographs, by Lt.-Colonel M. N. MacLeod, R.E. (Geographical Journal, June 1919).

12. ||Reminiscences of the Map of Arabia and Persian Gulf, by Lt.-Colonel F. F. Hunter, D.S.O., I.A. (Geographical Journal, December 1919).

13. ||Central Kurdistan, by Major K. Mason, M.C., R.E. (Geographical Journal, December 1919).

14. ||Surveys in Mesopotamia during the War, by Lt.-Colonel G. A. Beazeley, D.S.O., R.E. (Geographical Journal, February 1920).

15. ‡A lecture on the Earth's Axes and Figure, by J. de Graaff Hunter, M.A. (The Observatory, May 1920).

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16. *A brief review of the evidence upon which the Theory of Isostasy has been based, by Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Geographical Journal, July 1920).

17. *A note on the topography of the Nun Kun Massif in Ladākh, by Major K. Mason, M.C., R.E. (Geographical Journal, August 1920).

18. *Notes on the Canal System and Ancient Sites of Babylonia in the time of Xenophon, by Major K. Mason, M.C., R.E. (Geographical Journal, December 1920).

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20. ‡Topographical Air Survey (with plates and maps), by Lt.-Colonel G. A. Beazeley, D.S.O., R.E. (Royal Engineers Journal, February 1921).

21. ‡Projection of Maps.—A review of some Investigations in the Theory of Map Projections, by A. E. Young, and Colonel Sir S. G. Burrard, K.C.S.I., R.E., F.R.S. (Royal Engineers Journal, March 1921).

22. ‡Report on Expedition to Kamet, 1920, by Major H. T. Morshead D.S.O., R.E. (Royal Engineers Journal, April 1921).

23. *The Circulation of the Earth's Crust, by Lt.-Colonel E. A. Tandy, R.E. (Geographical Journal, May 1921).

24. §Johnson's Suppressed Ascent on E 61, by Major K. Mason, M.C., R.E. (Alpine Journal, November 1921).

25. *Stereographic Survey. The Autocartograph, by Lt.-Colonel M. N. MacLeod, D.S.O., R.E. (Geographical Journal, April 1922).

26. ‡The "Canadian" photo-topographical method of Survey, by Captain and Bt. Major E. O. Wheeler, M.C., R.E. (Royal Engineers Journal, April 1922).

27. §The Survey of Mr. W. H. Johnson in the K'un Lun in 1865, by Major K. Mason, M.C., R.E. (Alpine Journal, November 1922).

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29. ||Trigonometrical Heights and Atmospheric Refraction, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (A Dictionary of Applied Physics, Vol. III).

30. Geodesy, by Colonel Sir G. P. Lenox-Conyngham, Kt., R.E., F.R.S. and J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Enc. Brit. 12th Edition, Vol. XXXI, 1922).

31. *The proposed Determination of Primary Longitudes by International Co-operation, by Colonel Sir G. P. Lenox-Conyngham, Kt., R.E., F.R.S. (Geographical Journal, February 1923).

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34. †Kishen Singh and the Indian Explorers, by Major K. Mason M.C., R.E. (Geographical Journal, December 1923).

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36. ‖Graphical methods of plotting from Air Photographs, by Lt.-Colonel L. N. F. I. King, O.B.E., R.E.

37. †The Demarcation of the Turco-Persian Boundary in 1913-14, by Colonel C. H. D. Ryder, R.E. (Geographical Journal, September 1925).

38. Geodesy, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Enc. Brit. 13th Edition, New Vol. ii, 1926).

39. ¶The De Filippi Expedition to the Eastern Kara-koram, by B. B. D. and Colonel Sir G. P. Lenox-Conyngham, Kt., R.E., F.R.S., M.A. (Nature, 13th February 1926).

40. †The Problem of the Shaksgam Valley, by Colonel Sir Francis Younghusband, K.C.S.I., K.C.I.E. (Geographical Journal, September 1926).

41. †The Shaksgam Valley and Aghil Range, by Major K. Mason, M.C., R.E. (Geographical Journal, April 1927).

42. A Break-Circuit for Pendulum Clocks, by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Bulletin Géodésique No. 14. April, May, June 1927, Paris).

43. †A Graphical Discussion of the Figure of the Earth, by A. R. Hinks, C.B.E., F.R.S. (Geographical Journal, June 1927).

44. ‡Survey on Active Service, by Captain G. F. Heaney, R.E. (Royal Engineers Journal, June 1927).

45. A Report on the Geodetic work of the Survey of India for the period 1924-27, by J. de Graaff Hunter, M.A., SC.D., F. INST. P., presented at the third meeting of the International Union of Geodesy and Geophysics, Prague, September 1927.

46. †The Stereographic Survey of the Shaksgam, by Major K. Mason, M.C., R.E. (Geographical Journal, October 1927).

47. †Figure of the Earth: correspondence by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (Geographical Journal, December 1927).

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50. Figure of the Earth—Presidential address by J. de Graaff Hunter, M.A., SC.D., F. INST. P., at the Section of Mathematics and Physics of the Fifteenth Indian Science Congress, Calcutta 1928 (Published by the Asiatic Society of Bengal, Calcutta).

51. †Note on Sir Francis Younghusband's Urdok Glacier, by Major Kenneth Mason, M.C., R.E. (Geographical Journal, March 1928).

52. ‡Some Applications of the Geoid by J. de Graaff Hunter, M.A., SC.D., F. INST. P. (The Observatory, June 1928).

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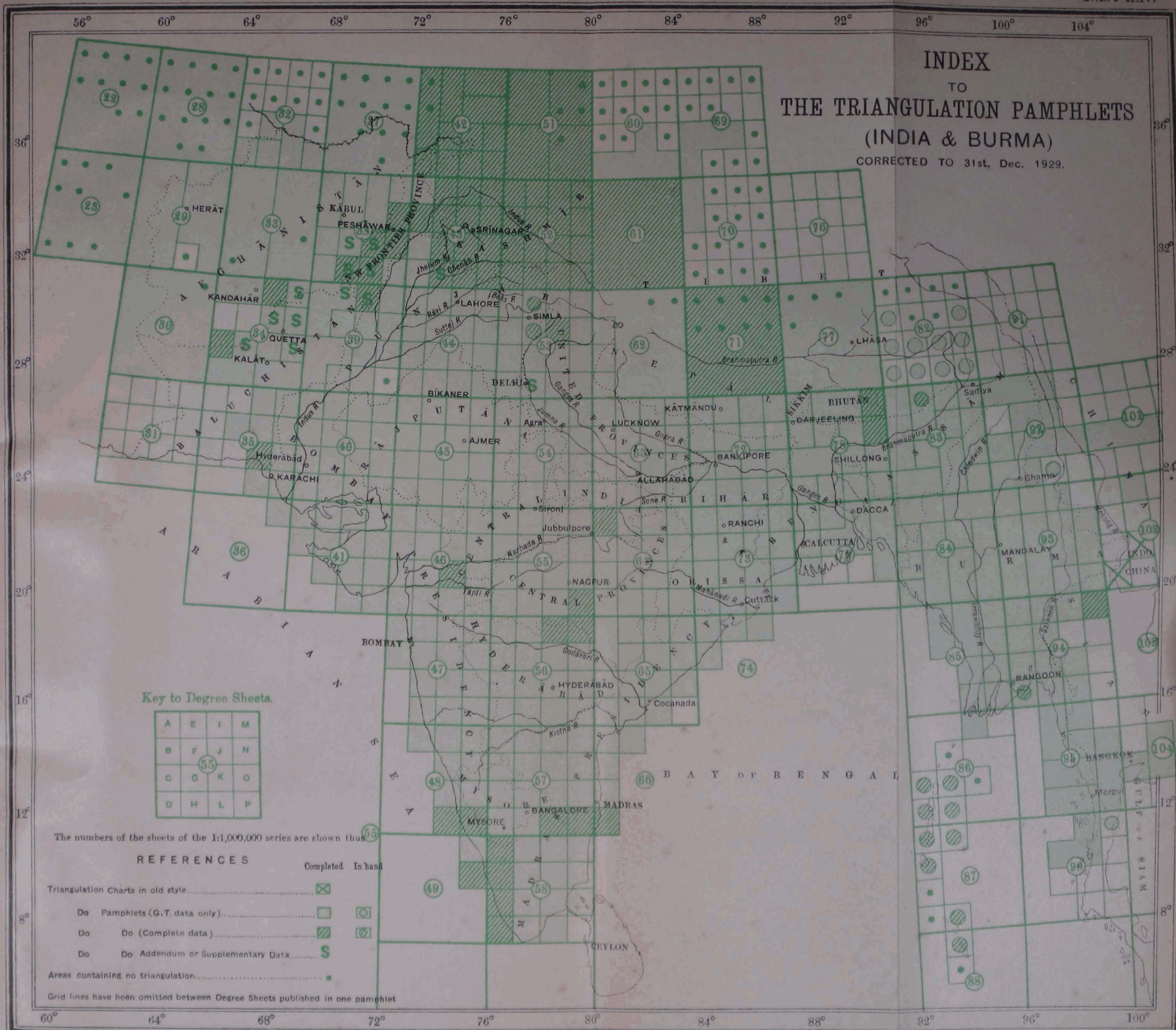
Chart XXVI



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Scale $\frac{1}{20,000,000}$ or 1·018 Inches to 320 Miles

Miles 100 50 0 100 200 300 400 500 Miles

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To accompany Geodetic Report Vol. V

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IRAQ, PERSIA & AFGHANISTAN
Corrected to 31st. Dec. 1929.

Chart. XXVII

Key to Sheet lettering International Sheet.

A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X

(J·37)

In this system each numbered sheet (e.g. J·37) covers an area of 4° in latitude by 6° in longitude. The degree sheets are designated thus. North J·37 / S

Scale $\frac{1}{15,000,000}$ or 1·013 inches to 240 Miles.

Miles 100 50 0 100 200 300 400 Miles

REFERENCES.

1. Sheet published ....
2. Sheet sent to Press (ready in Mss. form) ....
3. Area containing no data ....

Note:—Grid lines have been omitted between Degree sheets published in one pamphlet.

Key to Sheet lettering Indian Sheet.

A	E	I	M
B	F	J	N
C	G	K	O
D	H	L	P

(2)

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