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TECHNICAL PAPER No. 8

Survey of India

THE HEIGHT OF MOUNT EVEREST

"A NEW DETERMINATION (1952–54)"

By

B. L. Gulatee, M.A. (Cantab.), F.R.I.C.S., M.I.S. (India)

Director, Geodetic and Research Branch, Survey of India

PUBLISHED BY ORDER OF
THE SURVEYOR GENERAL OF INDIA

1954

Price Three Rupees or Five Shillings.

Corrections to Technical Paper No. 8,
The Height of Mount Everest "A New Determination (1952–54)"

Page i, Preface, para 4, line 2.—

After 1954, *add* the following :—

"It aims at providing a clear presentation of the issues involved and no exhaustive bibliography of previous attempts at calculating this height is given".

No. 1, dated 23–6–55.

Page 2, para 1, line 29.—

For '0·05' *substitute* '0·06'.

No. 2, dated 23–6–55.

Page 9, para 6(b), line 12.—

After the word respectively *enter* the following :—

"The heights obtained were as follows :—

	Height in feet	
	Mayām h.s.	Lāori Danda h.s.
From Ladnia T.S.	10,948·7	11,878·0
,, Chatra v.s.	10,946·5	11,875·8
,, Darjeeling Observatory h.s.	10,951·5	11,880·8"

No. 3, dated 23-6-55.

Page 13, para 8, line 2.—

For the words "Tavistock Theodolite" *substitute* "Wild T 2 Theodolite".

No. 4, dated 23–6–55.

Page 13, para 8, line 3.—

For the words "Geodetic Wild Theodolite" *substitute* "Geodetic Tavistock Theodolite".

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AIR PHOTOGRAPH OF MOUNT EVEREST FROM THE SOUTH WEST.

Reg. No. 3199 D'50—625'54.

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

PREFACE

Mount Everest is located on the Nepāl-Tibet border and is the pride of the Great Himālayan range. It is about 10,000 feet higher than Kilimanjaro, Africa's highest mountain, whose height has just been re-determined precisely[1], and even the highest peaks of U.S.A. would rank as its minor satellites.

The height of Mount Everest accepted by the Survey of India is 29,002 feet ; this has endured for over a century and the last digit of 2 has intrigued the expert and the lay-man alike for a long time. Several other values such as 29,050, 29,080, 29,141 and 29,149 have been quoted for it from time to time and with the growing enthusiasm regarding all matters pertaining to Mount Everest, certain half truths keep on getting printed in the semi-popular and even geographical and scientific literature. For instance, in the wake of the disastrous Assam earthquake of 1950, a story found wide circulation in U.S.A. that Mount Everest was pushed up and that the geologists now consider its height to be 29,200 feet. Similarly in the *London Times* (December 3, 1951), a correspondent asked for the most recently determined height of Mount Everest. He was told in reply by a wiseacre that 29,140 feet was the latest figure from revised computations and "Until Mr. Shipton or some other climber stands gasping on the summit with an aneroid in his hands, this seems to be the best that science can do".

To dispel such popular erroneous impressions, the author brought out a paper[2] which gave an appraisal of the peculiar difficulties associated with the determination of the heights of lofty mountain peaks. Calculations of such heights is dependent on a number of important factors in a field which is mainly the preserve of specialists. It was explained in the above paper that because of lack of proper observational material and geodetic data the older calculation of the height of Mount Everest was entirely inadequate and there was urgent need for scientifically planned observations to this peak from mountains in Nepāl not far from it.

This paper describes in detail the work undertaken for this purpose during the years 1952, 1953 and 1954. Very careful planning was required to ensure an adequate number of observations, bearing in mind the difficulties of terrain and lack of transport and communications.

The first desideratum was to carry a triangulation series as close to the peak as possible. This is a costly item and would have been unjustifiable if carried out solely for the purpose of determining the height of the peak. Fortunately a chain of minor triangulation was run in Nepāl in the years 1946–47 to provide control for irrigation projects. This was reinforced by 3 measured bases and 3 spirit-levelled connections and the triangulation was extended to the north in 1952–53, so that its most northerly stations were at distances of 30 to 40 miles from the peak (see Chart II). Mount Everest was observed from 8 stations of this series ranging in height from 8670 to 14762 feet and great care was taken to ensure that the heights of these take off stations were well fixed in terms of spirit-levelling.

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[1] 'The calculation of the height of Kilimanjaro', by W.L. Dickson. Empire Survey Review, Jan. 1954, p. 206.

[2] "Mount Everest—Its name and height", by B. L. Gulatee, Survey of India, Technical Paper No. 4.

The previous attempts to fix the height of the peak were also hampered by complete lack of geodetic data. In 1953–54, a comprehensive programme of plumb-line deflections and gravity observations was carried out to delineate the geoidal rise under Mount Everest. These observations are unique in many ways and are of great significance for revealing the mechanism of compensation of this interesting region.

Topo triangulation extending west from Darjeeling was carried out by Messrs. R. S. Chugh, U. D. Mamgain, R. L. Sharma and N. N. Dhawan during the years 1946–53 (Chart II); the extension triangulation by Capt. M. M. Datta (1953); vertical angle observations by Messrs. M. M. Datta and J. B. Mathur (1952–53–54); the plumb-line deflections by Shri J. B. Mathur and the gravimeter observations by Shri A. N. Ramanathan (1954). Much credit is due to the observers for carrying the work to a successful conclusion under arduous conditions, especially as they were not well equipped for climbing on high mountains.

The analysis and reductions of the new data have entailed heavy work in which I have received much assistance from Shri C. B. Madan and the staff of the Computing Section at Dehra Dūn. These are described fully in this paper and are compared in detail with the earlier observations.

The new value obtained is 29,028 feet which, it is hoped, is not likely to be in error by more than 10 feet. It will serve no useful purpose to push the accuracy further by more observations as the seasonal fluctuation of snow on the summit could well be of this order of magnitude. The older value of 29,002 feet was vague and was computed in a most incomplete manner, e.g., with a definitely wrong value of refraction and with no regard to the datum surface. It has always been suspected that it erred on the moderate side and some enthusiasts have regarded the peak to be some 200 feet higher than the quoted value. They will, no doubt, be disappointed. The accepted value 29,002 feet has been critically appraised in para 9 and it will be seen that the implications of this new figure for height are very different from those of the old one and the two are really not comparable. The fact that they are so close together is due to fortuitous cancellation of the effects of certain important physical factors which had been neglected in the previous computation.

My thanks are due to Brigadier G. Bomford for helpful discussions both orally and by correspondence.

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Director, Geodetic & Research Branch.

DEHRA DŪN:
Dated 25th Oct. '54.

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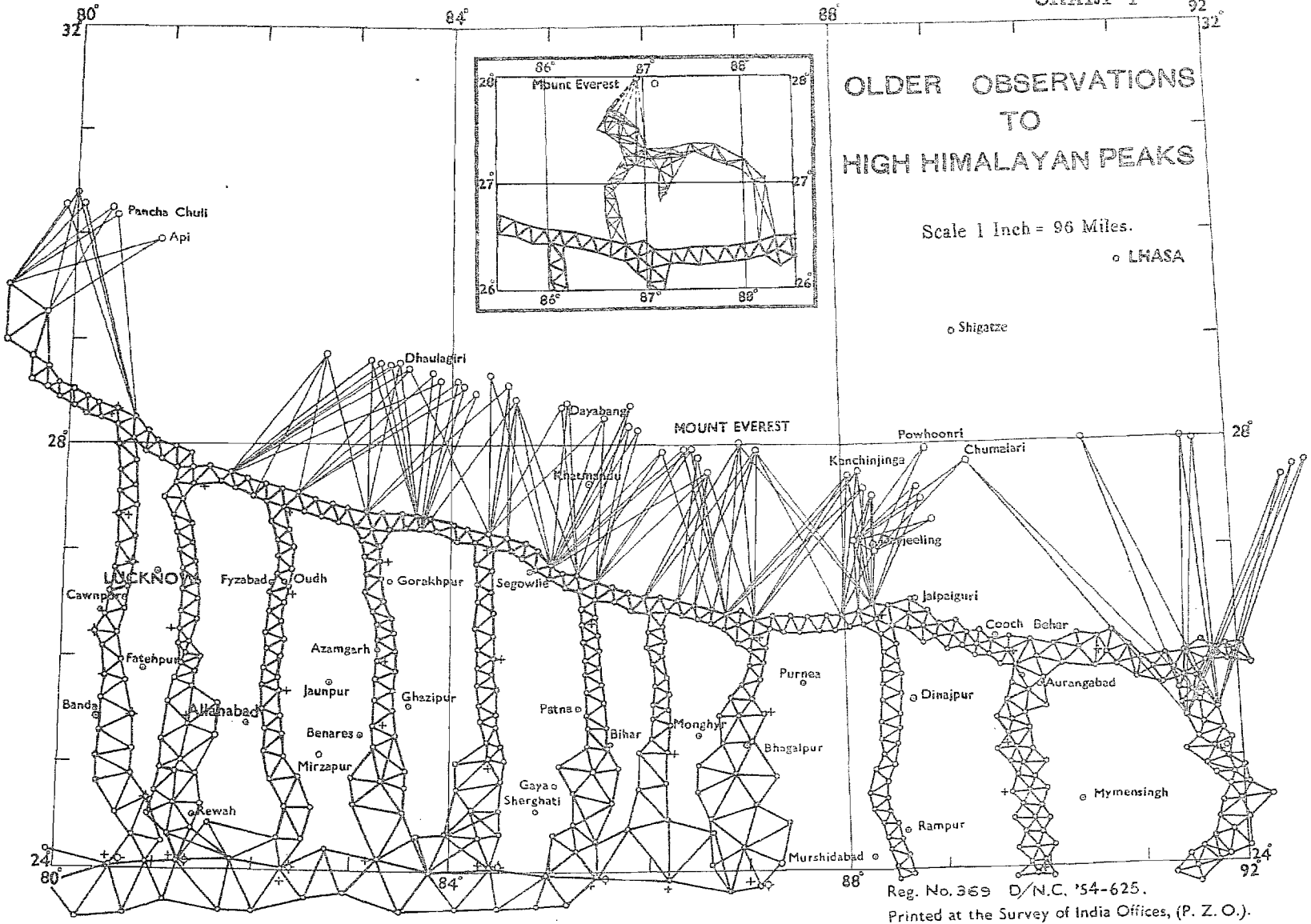
CHART I

OLDER OBSERVATIONS TO HIGH HIMALAYAN PEAKS

Scale 1 Inch = 96 Miles.



Reg. No. 369 D/N.C. '54-625.
Printed at the Survey of India Offices, (P. Z. O.).

THE HEIGHT OF MOUNT EVEREST

BY

B. L. GULATEE, M.A. (CANTAB.), F.R.I.C.S., M.I.S. (INDIA)

1. **Heights of Himālayan Snow Peaks.**—The North-East Longitudinal Series, covering a linear distance of about 740 miles from the Dehra Dūn base to Sonakhoda base in Bihār, was observed in the years 1846 to 1851, with theodolites ranging in size from 15 inches to 36 inches. It was originally intended that this series should run along the Nepāl mountains but inspite of repeated attempts the Nepāl Government did not accord permission for observations along this route and the plan had to be altered. After crossing the hills of Garhwāl, the triangles were made to pass through the malarious and unhealthy tracts at the foot of the Himālayas. The country being flat, towers about 20 to 35 feet high were used to secure inter-visibility of stations. Chart I illustrates how the Himālayan peaks in Nepāl were observed as intersected points by surveyors in 1849 to 1855 from distant low lying stations of this series. For comparison, the modern stations from which Mount Everest has been observed are shown in the inset.

The heights of the Himālayan peaks evoked great interest in the Survey of India even in the early days and in a circular issued to the Great Trigonometrical Survey parties in the field in 1845, the Surveyor General Sir Andrew Waugh wrote "The lofty snow peaks situated north of Nepāl are the most stupendous pinnacles of the globe. Their heights and relative positions should form permanent objects in the geodetical operations". His instructions to Nicholson in 1849, when he was observing along the North-East Longitudinal Series, were "You should be in the observatory before sunrise and all prepared to commence horizontal angles as soon as it is light. The vertical angles may be taken from 8 to 10 o'clock A.M.". It is extremely difficult to get visibility in the afternoon over such long rays and the last sentence was added to ensure at least some observations being taken at other times, so that the opportunity to observe the high peaks was not entirely lost.

When viewed from the plains of Nepāl, Mount Everest, inspite of its towering personality, does not appear to over-shadow the array of surrounding peaks. In fact, some of the peaks, on account of their nearness, give the illusion of being higher and when observations were taken to Mount Everest, there never was the slightest suspicion that it was the highest mountain in the world. The general belief at the time was that Kānchenjunga was the world's loftiest peak. The observers took an immense number of horizontal and vertical angles to the snow peaks from the principal stations of North-East Longitudinal Series. They could not possibly discover individual local names from such long distances and quite a number of peaks were characterized by figures and Roman numerals. Mount Everest was simply labelled 'b' by Armstrong, 'y' by Waugh and Lane and 'h' by Nicholson. This was changed to peak XV at headquarters by Hennessey.

A reference to some old manuscripts has revealed that J. W. Armstrong while observing the Gora Meridional Series had thrown a single ray to Mount Everest in 1847 from a distance of about 200 miles. The observation consisted of a single determination of distance and a vertical angle. The value of the height which he obtained was 28,799 feet.

It was later observed from the following six stations of the N.E. Longitudinal Series in 1849–50:—Jarol, Mirzāpur, Janjipati, Ladnia, Harpur, and Minai (see charts I & II).

These are stations in the plains at an average height of about 230 feet above mean sea-level and towers (about 20 to 32 feet high) had to be built on them to make them intervisible for triangulation. The stations were about 110 miles away from the mountain. Once it was known that this was the world's highest peak, great pains were taken over the reduction of the data. In particular, a lot of attention was paid to refraction which plays a dominant role when the rays are long.

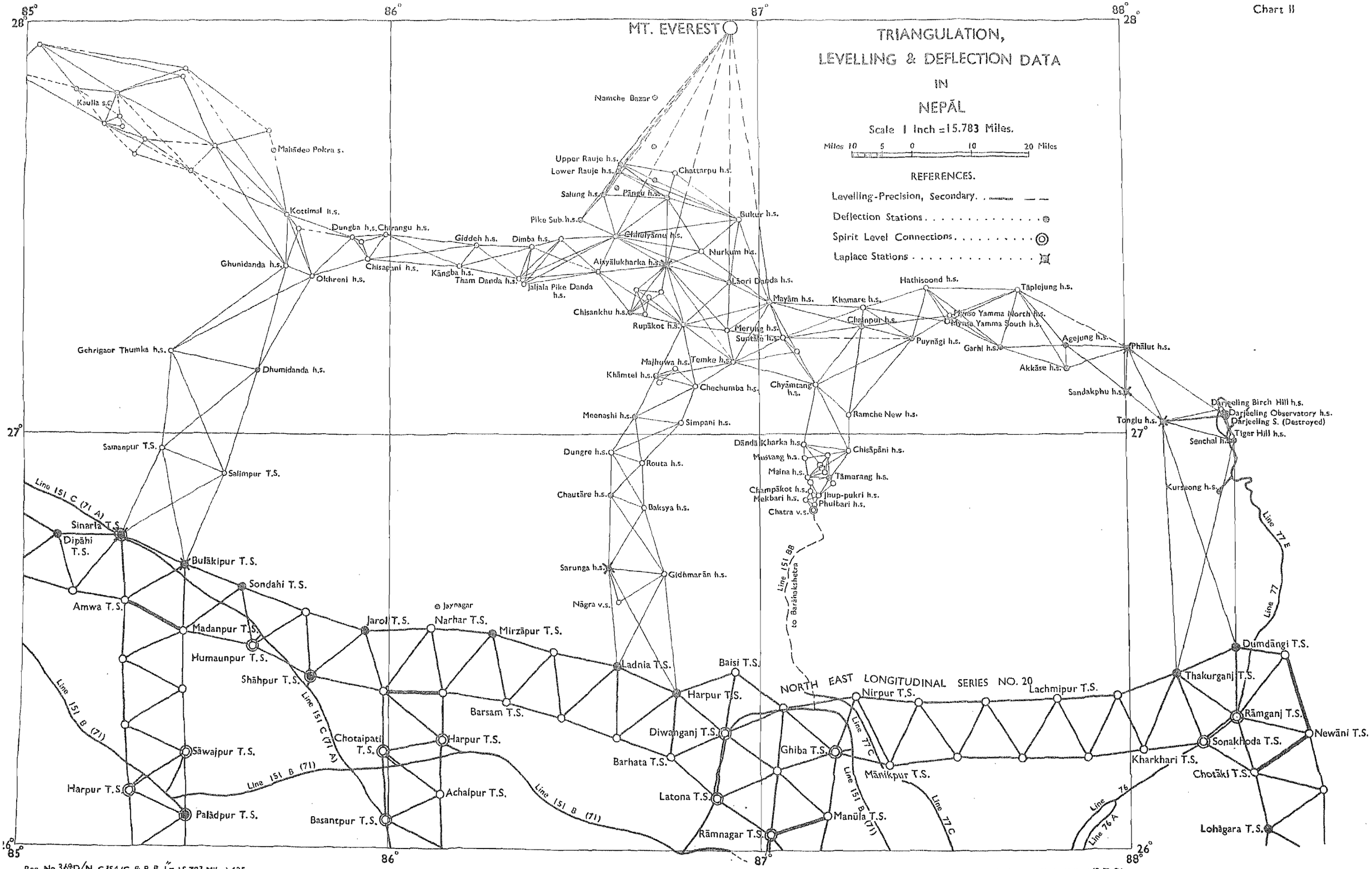
No narrative account giving details of the old height computations of Mount Everest is forthcoming. Table I gives a synopsis of the observations; the heights calculated from each station are given in column 9, the mean value being 29,002 feet, which is the figure adopted up to the present time. This table has been compiled from the original computation volumes.

It is on record that Sir Andrew Waugh took elaborate observations for determining the curvature of the path of a ray of light between a number of peaks in the outer Himālaya and the plains of Bengal by means of simultaneous reciprocal observations. The coefficients of refraction k were obtained by giving due weight to the number of observations and the length of the sides. From column 10 of Table 1, we see that the k's are given to 6 places of decimals and are different for different stations. The basis for the derivation of so many fictitious digits is nowhere stated but it is representative of the trends in those days. Actually, the concept of k for such long rays is erroneous and although with our present knowledge we can do much better, still for such long rays, the evaluation of refraction is even now subject to considerable uncertainty. In any case, the figures adopted for k (·07 to ·08) were very much at fault; they should have been of the order of 0·05. No account was taken of plumb-line deflections either, as ideas about them were rather vague in those times, nor was the necessary information available for fixing the datum above which the height was reckoned.

In the seasons 1880–83 and 1902, further observations were taken from stations in the Darjeeling hills in the course of the normal survey programme. (See Table 2). These stations were also too far, being at an average distance of 90 miles from Mount Everest, but they had the advantage of being at a higher level. Assuming a coefficient of refraction of 0·05, Burrard calculated the height of Mount Everest from these observations in 1905 and arrived at the value of 29,141 feet*. He also recomputed the older observations and fixed the coefficients of refraction for the various rays by trial and error in such a way that the mean result came out to be 29,141 feet. Here again plumb-line deflections were not utilized and this value is also above an undefined datum. But it has attracted considerable attention in recent years. The Americans have published it on their maps and such an eminent mountaineer as F. S. Smythe in his book "Mountains in Colour" published in 1949 made a definite statement that the true height of Mount Everest was 29,141 feet. He attributed the difference from 29,002 feet to be due to the fact that "the mass of the Himālayas puts the bubble of a theodolite very slightly out of plumb to the centre of the earth" which of course is not the true explanation.

Before we describe the new observations, it would be well to recount some of the factors which have an important bearing on the problem of the determination of heights of inaccessible peaks.

* "A sketch of the Geography and Geology of the Himālaya Mountains and Tibet," by Col. S. G. Burrard and H. H. Hayden, Part I, 1907, p 26.



Reg. No. 369 D/N. C. '54 (G. & R. B. 1" = 15·783 Miles)-625.

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

2. **Refraction.**—It was realized even in the earliest days that refraction was a most potent factor in evaluating the heights of the high mountain peaks as observed from long distances and much effort was expended in deriving the appropriate coefficients of refraction. For rays of 115 miles or so, an error of 10^{-5} in k produces an error of a foot or so in height and this is why in the older computations the k's were taken to 6 places of decimals, because they computed each derivation of height to one place of decimal. No temperature and pressure observations were taken and it is not known how such a large number of digits were selected—possibly the ruling consideration was that there should be a good measure of agreement between the heights derived from various stations. In the light of modern knowledge we know now that the coefficients of refraction adopted in the older computations were grossly in error and the results from the various stations were quite heterogeneous being burdened with varying systematic errors.

The curvature of a ray of light and consequently its refraction depends on temperature T, pressure P and temperature gradient β of the atmospheric layers through which a ray passes, and is changing all the time. To obtain it accurately, observations for air density are required all along the ray at the time of observation. This is never feasible in practice and certain assumptions have to be made. The simplest method is to assume a value of coefficient of refraction k for the ray and get refraction from the formula $\Omega = k\chi$, where χ is the length of the ray in angular measure. This concept of k is, however, not valid for long rays with their extremities at very different elevations. It is only applicable to an infinitesimal part of a ray, being dependent on the values of β, P and T prevailing there and these vary throughout the day.

Air being compressible, has a greater density near the earth because of the greater mass above it. When it rises, it expands and is cooled without transfer of heat and thus changes of temperature can occur in an ascending or descending mass of air due to different pressures. Theory shows that this dynamic cooling of dry air due to expansion is 5·5°F. per 1,000 feet. This is called the Adiabatic Lapse Rate. The above figure, however, is for dry air ; the presence of moisture has a considerable retarding effect on the cooling and a good average value is 3·2°F. per 1,000 feet. Much research (theoretical and practical) has been carried out on refraction since the beginning of this century and it has been found that the major portion of the variation of refraction is caused by the large diurnal fluctuations of the temperature gradient. In the plains, the lapse rate may change by as much as 200% in the course of a day and in the layer close to the ground surface, the extent of variation can be very considerable. The modern practice to overcome irregular effects of refraction is by selecting a particular time of observation, called the time of minimum refraction. This happens to be near mid-day, as it is only at this time that variations in the temperature gradient from day-to-day are least. On this account, the normal reciprocal vertical angle observations are confined to this time in the usual routine of topographical surveys and if the extremities of the ray are not at very different elevations, refraction is assumed to be the same at the two ends.

The snow peaks of the Himālayas, however, present one great difficulty in that reciprocal observations are not possible. Even with our present knowledge it is not possible to give a theoretical formula for refraction, which will be universally applicable for all lengths of rays, because intervening lapse rates may be very different from the accepted ones.

Experience shows that even for a triangulation series with comparatively short sides, heights derived from reciprocal observations differ systematically according to the square of the length of the ray, indicating clearly that the actual temperature gradients are different from the tabulated ones.

The only practical way of overcoming the uncertainty of refraction in such a case is to observe from high hills close to the peak. The diurnal variation of lapse rate is comparatively small in this case and it is not absolutely essential to confine the observations to mid-day. The values of refraction for the various rays in this paper have been calculated by using the following formula for the coefficient of refraction :—

$$k = 50{,}000 \frac{P}{T^2} (0 \cdot 0187 + \beta),$$ where T is in absolute degrees F and β is degrees F/ft.* β has been taken as $3 \cdot 2^\circ$F/1,000 ft.

For steep rays, like the ones to Mount Everest, where the temperature and pressure conditions at the two ends are very different, it can be shown that a value of k pertaining to a point 1/3rd up along the ray gives a very good approximation. It will be shown in a later section that the resulting error in height, due to probable fluctuations in β for the observations under discussion, is negligible.

3. **Datum.**—The heights of points on the earth to be comparable with one another have to be reckoned above the same reference surface. Several such reference surfaces are available some of which are real while others are imaginary. Two of the most important ones are the reference spheroid of the country on which the triangulation is computed and the mean sea-level surface (geoid). In India, the latitude and longitude for mapping purposes are computed on a true spheroid called the Everest spheroid. The geoid is, however, not a true mathematical surface on account of the irregular distribution of land and sea. One can consistently work on either surface, i.e., one can quote either spheroidal or geoidal heights provided one does so uniformly. There are, however, certain pros and cons regarding the choice of the reference surface which need clarifying at the outset. The interaction between these two surfaces involves some abstruse conceptions and even the experts have tripped over it in the past.

The geoid, although irregular, has an actual physical existence and the surveyor's or engineer's level at each setting sets itself parallel to it. Starting with the mean sea-level at a given coastal observatory, a geodetic surveyor can trace the geoid in great detail within the limits of observational and instrumental errors. The reference spheroid, on the other hand, has a mythical existence and can only be located by means of the geoid with the help of geodetic and astronomical observations. While it is the only suitable surface for reckoning latitudes and longitudes, it is not so suitable as a height datum. Its adoption would lead to non-uniformity, as different countries use very different spheroids as their figures of the earth.

Our predecessors in the last century knew levelling and so were able to obtain geoidal heights thereby. In the plains by the measurement of vertical angles they were also getting geoidal heights, although they were often unaware of it. They were not able to obtain heights above the Everest spheroid, as they lacked the information regarding the separation of the geoid from the spheroid. In fact, they quite often confused the two surfaces.

* "Geodesy" by G. Bomford, p. 159.

In the plains, the use of geoid as datum surface for height offers no particular difficulty. Levelling with suitable corrections can be made to give the geoidal height direct. The usual method employed is that of vertical angles. The heights given by this method are vague and further considerations are necessary to reduce them either to the geoid or to the spheroid. The theodolite when levelled, defines the geoidal normal and so the observed vertical angles are really geoidal angles. The usual height formula employed in triangulation makes two drastic assumptions, viz :—

(*a*) that the observed angles are spheroidal, and

(*b*) that the geoid is a sphere.

It can be proved that, with conditions as they exist in nature, reciprocal vertical angle observations in normal topographical triangulation give good orthometric geoidal heights inspite of the apparently erroneous assumptions involved in the computations. For longer rays as are met with in geodetic triangulation, the precision of heights becomes less and for high Himālayan peaks, where reciprocal observations are not feasible, the trigonometrical method gives poor geoidal heights. Hence, the older determinations of high Himālayan peaks were weak. To get heights of such peaks with any degree of accuracy requires quite different considerations as will be seen later. It is important to realize that spheroidal heights can only be obtained from triangulation if every observed angle is corrected for deflections of the plumb-line and this has never been done.

The geoidal height of high mountain peaks can only be derived via the reference spheroid used and this necessitates that the relation between the two surfaces should be known very accurately.

The full specification of a reference spheroid involves 5 quantities (a, b, η_0, ξ_0, N_0) at the datum selected as the origin of triangulation, where a, b denote the semi-axes, η_0, ξ_0 the plumb-line deflections and N_0 the separation between the geoid and the spheroid. In India, the axes (a, b) of the Everest spheroid which is still in use for mapping, were determined in 1830 and the datum chosen was Kaliānpur. In the 1850's, when observations to Mount Everest were taken, ideas about such concepts as plumb-line deflections and reference spheroids were rather vague and not much attention was devoted to η_0, ξ_0, N_0. In fact, the measured base-lines in those days were reduced to geoid assuming it to coincide with spheroid everywhere. As geodetic knowledge progressed, it became imperative to allocate a value to N_0. It was defined to be zero at Kaliānpur in 1926 using the criterion that this choice made the mean height of the geoid above the spheroid under the ten Indian bases that had been measured up to that time to be zero. The year 1925 brought about the advent of the International spheroid, which is a considerable improvement on the Everest spheroid. For all scientific studies of the geoid, this is the spheroid now used in India. It was defined to be 31 feet above the geoid at Kaliānpur in 1927 and the relation between the above two spheroids in India has been shown graphically by the author[1]. It is only when the concept of such a reference spheroid is introduced to serve as an intermediary that the problem of heights of high Himālayan peaks takes on a coherent form. The older figures of 29,002 feet and 29,141 feet quoted for the height of Mount Everest are rather vague in that they do not refer to any defined datum.

[1] "The separation between different spheroids", by B. L. Gulatee, Survey of India, Geodetic Report, 1934, Chapter VIII.

4. **Heights of Observing Stations.**—The table below gives the heights of the 6 stations from which Mount Everest was observed in 1849–50 :—

Station of observation	Height used in old computations	Height published	Difference
	feet	*feet*	*feet*
Jarol T.S.	231	220	—11
Mirzāpur T.S.	254	245	— 9
Janjipati T.S.	263	255	— 8
Ladnia T.S.	242	235	— 7
Harpur T.S.	226	219	— 7
Minai T.S.	237	228	— 9

Column 2 gives the heights used in the older computations and column 3, the present accepted heights after adjustment to spirit-level values. It will be seen that the mean height of the observing stations has changed by about 8 feet. As a result of this the height of Mount Everest was changed to 28,994 feet on the charts of triangulation in the General Reports for the years 1892 to 1903. In 1903, the old value of 29,002 was restored as it was realized correctly that the change was premature in that any new value would be burdened by much larger errors*.

The values of the starting stations of 1880 observations have also undergone changes as a result of later spirit-levelled connections as the following table will show :—

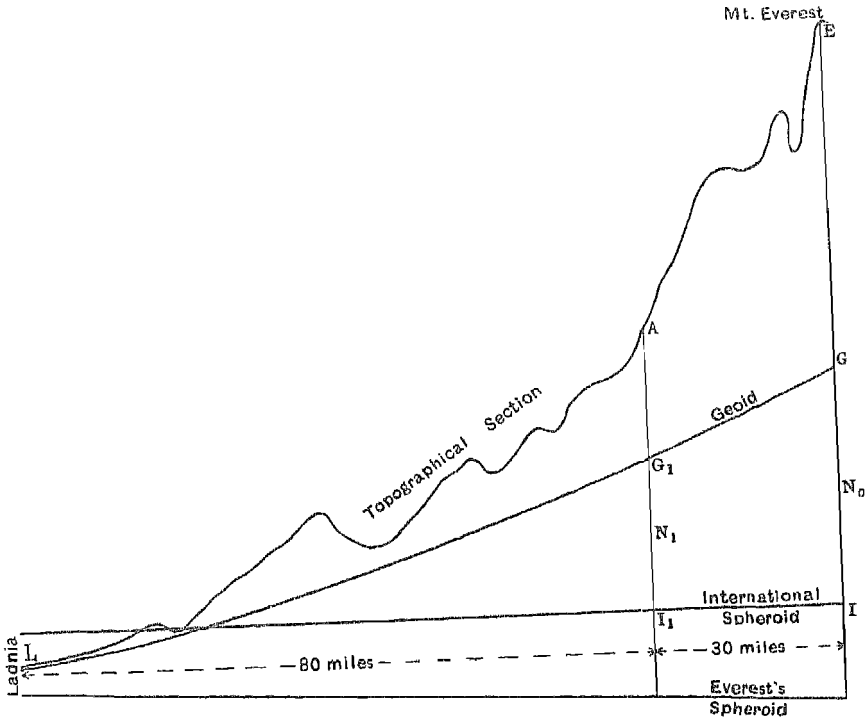
Station	Year of observation	Height accepted in older computations	Present accepted values
		feet	*feet*
Suberkum h.s.	1881	11,641	..
Tiger Hill h.s.	1880	8,507	..
Sandakphu h.s.	1883	11,929	11,915
Phalūt h.s.	1902	11,816	11,798
Senchal h.s.	1902	8,599	8,584

In order to avoid any uncertainty on this account, special care was taken to provide an adequate number of spirit-levelled connections in the new triangulations which have been used to provide stations of observation for the new work.

5. **Outline of the New Method.**—The three main sources of uncertainty in the older determination are—(a) refraction, (b) neglect of deflections and (c) non-specification of the datum surface.

* "A sketch of the Geography and Geology of the Himālaya Mountains and Tibet" by Col. S. G. Burrard, and H. H. Hayden, Part I, 1907, pp 26–27.

The diagram below illustrates how these have been overcome in the new method.



LE denotes the cross-section of the topography between Ladnia (latitude 26° 25′ 50″·32, longitude 86° 37′ 15″·04), a point in the plains of Bihār and Mount Everest; A is a station about 12,000 feet high at a distance of 30 miles (say) from Everest. The sections of the geoid, International spheroid and Everest spheroid between these points are also shown in the diagram.

Our objective is to get EG the height of the peak above the geoid and this can be done via the intermediary of the International or Everest spheroids. For our reductions, we have chosen the former. If N_1, N_0 denote the geoidal rises under A and E respectively, we have $EG = AG_1 + (EI - AI_1) - (N_0 - N_1)$. The spheroidal height difference $(EI - AI_1)$ is determined by vertical angle observations (corrected for plumb-line deflections) which are burdened with refraction. In the older observations AE was of the order of 100 miles and in such a case refraction produces an insuperable difficulty. It is subject to large diurnal variation and its computation from theoretical considerations, can be in error by considerable amounts even if the observations are confined to the time of minimum refraction. In the present work, the vertical angles to Everest are taken from a number of high peaks (typified by A), distant about 35 miles from the peak. These stations are connected to the main G.T. series (N.E. Longitudinal Series) by a short-sided triangulation. Refraction at these altitudes, being neither so large nor so erratic as in the low lying plains, can be tackled much more successfully. The correction to height due to refraction is only one-tenth of that of the earlier observations. At such high levels, the outstanding items that have to be reckoned with are plumb-line deflections and geoid; errors due to refraction are secondary, provided there are no grazing rays.

It might be mentioned that the height of Mount Kilimanjaro (19,340 feet), the highest mountain in Africa has recently been redetermined[1]. It was possible for the observers to get to the mountain top with their theodolites and to carry out reciprocal observations. No account was taken of the plumb-line deflections, as Kilimanjaro is not such a large mass. It is on account of the gargantuan mass of the Everest producing exceptionally large deflections and deformation of sea-level and the fact that no observational work is possible on its summit that so many refinements have to be taken into account.

It can be shown that the ordinary trigonometrical computations of reciprocal rays of a short-sided triangulation give a good value of the geoidal heights. The geoidal height AG_1 of A is thus precisely known.

The carrying out of short-sided triangulation close to the peak is thus an important step forward. Not only does it do away with the major uncertainty due to refraction but it also gives good geoidal heights for observation stations without worrying about deflections.

The estimation of ($N_0 - N_1$), the anomalous rise of the geoid in the last 35 miles, has to be based on clues provided by deflection and gravity observations. Deflection observations have been carried up to Nāmche Bazār, a distance of only 18 miles from Mount Everest.

In the older derivation of heights, neither the deflections nor the relation between the geoid and the reference spheroids were available and the derived heights did not pertain to any specific surface, as no account was taken of these important factors.

6. **Triangulation and Height Data.**—Chart II shows the triangulation used for deriving the new value of the height of Mount Everest. The various topographical triangulations emanating from the stations of the North-East Longitudinal Series were executed in the years 1946–53 to provide control for irrigation projects in connection with the Kosi Dam. Four Laplace stations and three base-lines were introduced in the circuit Thakurganj–Dumdāngi–Tonglu–Sandakphu–Garhi–Chyamtang–Temke–Khāmtel–Meenashi–Dungre–Chautāre–Sarunga–Ladnia. This circuit closed with an error of 1 in the 5th place of log side, 2″ in azimuth, —0″·07 in latitude and —0″·11 in longitude, which is very satisfactory.

For the purpose of providing observation stations to Mount Everest, an extension triangulation was carried out in 1952–53, starting from the sides Mayām h.s.–Lāori Danda h.s. and Aisyālukharka h.s.–Chhulyāmu h.s. of the above work. This extension triangulation provided eight stations at heights ranging from 8,670 to 14,762 feet, from which vertical angles were observed to Mount Everest in the years 1952–53 and 1953–54.

(*a*) *Position of Mount Everest.*—The old position of Mount Everest was rather doubtfully fixed. It was observed from seven stations of the North-East Longitudinal Series, but no two of them were intervisible. The angles had to be deduced through reference stations other than the observing stations with the help of azimuths computed from co-ordinates. The original computed values of the position were :—

Latitude	27°	59′	16″·748
Longitude	86	58	05·852

[1] Empire Survey Review, Jan. 1954, No. 91, Volume XII, p. 206.

Chart III

TRIANGULAR MISCLOSURES IN HEIGHT

Scale 1 Inch to 4 Miles

Miles 5 4 3 2 1 0 5 Miles

86°30′ 45′ 87°00′

27° 45′

30′

27° 15′

Upper Rauje h.s.
Lower Rauje h.s.
Chattarpu h.s.
Salung h.s.
Pāngu h.s.
Pike Sub. h.s.
Bukur h.s.
Chhulyāmu h.s.
Nurkum h.s.
Alsyālukharka h.s.
Lāori Danda h.s.
Mayām h.s.
Rupakot h.s.

+1·9
−0·8
+0·5
+0·4
−1·3
+2·6
−0·8
+0·8
+1·0
+0·7
+3·6
−1·0
−0·6
−0·3
−0·5

+40·4 −3329·2 −39·5 −38·6 −3105·2 −3105·3 −1699·6 −2124·5 +3529·6 +2125·6 +3105·4 +1700·1 −1699·9 +3529·9 +2126·6 +3569·9 −3569·9 −1365·3 +1354·7 −427·8 +426·2 +424·6 +399·0 +400·0 −400·9 −1498·7 +1498·0 −1073·3 +2212·9 +624·8 −2214·8 +1354·0 −2216·6 −1073·1 −623·8 −1900·9 +1900·6 +1900·2 +1497·3 +1072·9 +1696·7 −1488·4 −1696·1 −1695·4 −1593·1 −1568·8 −2500·0 −1591·8 −622·8 +1590·4 +1567·8 +2500·5 +1491·3 −3184·8 +22·6 −912·8 −3183·8 +1494·1 +3182·8 +3206·8 +3204·9 −141·7 −3207·8 −3206·4 −23·0 −23·3 +1566·7 +909·4 −3208·7 −3207·9 −3348·7 −933·5 +932·1 +2500·9 +906·0 +930·6 +142·1 −3349·0 +142·4 +3349·2

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The co-ordinates were recomputed in 1905 using the adjusted co-ordinates of the observing stations as derived from the simultaneous adjustment of the principal triangulation of India. The longitude was also brought into terms of the latest value of the longitude of the Madras Observatory. The co-ordinates adopted were

Latitude	27°	59′	16″·22
Longitude	86	55	39 ·91

Although not important from the point of view of height determination, the co-ordinates of Mount Everest have been refixed from three stations, viz., Bukur h.s., Chhulyāmu h.s. and Upper Rauje h.s. during 1953.

The results of the two triangles are very accordant, the mean value being

Latitude	27°	59′	15″·85
Longitude	86	55	39 ·51

Mount Everest has thus to be shifted by about 40 feet southwards and westwards from its accepted position.

(*b*) *Heights.*—From a perusal of Chart II, it would appear that the triangulation heights are well controlled by spirit-level connections. The heights for the computations of the present series take off from Diwanganj T.S. (72 J), Chatra v.s. (72 N) and Darjeeling Observatory h.s. (78 A). Their spirit-levelled heights are as follows :—

	feet
Diwanganj T.S.	188·89
Chatra v.s.	378·68
Darjeeling Observatory h.s.	7,144·85

The heights of Mayām h.s. and Lāori Danda h.s. were derived independently from 3 routes,—from Ladnia T.S., from Chatra v.s. and from Darjeeling Observatory h.s. respectively. The heights derived from these three routes have been weighted in the proportion of 2, 3 and 1 respectively. The result from Chatra v.s. has been given the greatest weight as apart from being shortest in length, it has the smallest triangular misclosures in height. The finally accepted values of the heights of Mayām h.s. and Lāori Danda h.s. are as follows :—

	Height in feet
Mayām h.s.	10,948
Lāori Danda h.s.	11,877

The triangular misclosures in heights of the main and extension triangulations (see Chart III) are very small ranging only from 0 to 4 feet and it was not considered worthwhile to adjust the extension triangulation by the method of least squares.

The final values of the heights of the 8 stations from which Mount Everest is observed are given below :—

	Height in feet		Height in feet
Mayām h.s.	10,948	Pike Sub. h.s.	12,059
Lāori Danda h.s.	11,877	Sollung h.s.	11,658
Aisyālukharka h.s.	8,670	Lower Rauje h.s.	13,357
Chhulyāmu h.s.	10,160	Upper Rauje h.s.	14,762

From the evidence of the triangular misclosures it can be safely inferred that these are correct to within 2 or 3 feet.

7. **Plumb-line Deflections and the Geoid.**—The rise of the geoid under the mighty range of the Himālayas has been the subject of much

speculation. Due to the paucity of deflection and gravity data in this region, no reliable estimate has so far been possible.

By taking a generalized section of the topography of the Himālayas and Tibet, Mader* reckoned that N (height of the geoid) under Himālayas would be 377 metres without isostasy and 40·7 metres with isostasy. He also estimated that the uncompensated geoid would rise by about 300 feet from the plains to a point under the summit of the Himālayas and Compensated geoid by 120 feet. Mader was not concerned with Mount Everest in particular and his figures can only be regarded as indicative of the orders of magnitude.

Deflection observations have been carried out during the last 3 years to delineate the geoid in the Mount Everest area. For this purpose, a lot of preparatory work was necessary for providing a good starting basis. The existing geoidal section along the foot-hills of the Himālayas from Dehra Dūn to Darjeeling was very weak on account of the paucity of prime vertical deflections.

In 1952, a chain of astrolabe stations (covering a linear distance of about 300 miles) was established at about 15-mile interval along the tower stations of the North-East Longitudinal Series. These observations provide a reliable value of the geoidal height at Ladnia T.S. (latitude 26° 25′ 50″·32, longitude 86° 37′ 15″·04), a point in the plains of Bihār. In 1953, work was extended from this point to Nāmche Bazār (latitude 27° 48′ 46″·5, longitude 86° 43′ 12″·0) which is distant only 18 miles from Mount Everest. The main effort was directed to establish stations as far as possible along the meridian of 86° 40′. A number of other surrounding stations were also observed to extend the knowledge of the geoid in this virgin region.

On account of the cost of transport, difficulties of rations, lack of communications and paucity of trigonometrical data to establish positions of stations by resection, it was not possible to put in as dense a mesh as would have been desirable and it was apprehended that the variations of deflections at such long intervals might be too ragged to allow of an accurate geoidal section being drawn. But the following will show that the data obtained is quite adequate for providing reliable geoidal information.

Chart IV shows the resulting deflections vectorially at the stations observed. As expected, these deflections exhibit several points of interest. In the plains, at a distance of 96 miles from Mount Everest, the deflections are northerly and easterly but are of small magnitudes. The northerly deflections increase rapidly till the foot of the hills is reached at Chautāre (height 2,615 feet, distance 70 miles from Mount Everest). From Chautāre to the hill station of Meenashi (6,318 feet), there is a decrease of 9″ in the meridional deflection and after that there is a steady increase of about 1″ a mile till the maximum value of 71″ is reached at Lower Rauje (height 13,357 feet, distance 30 miles from Mount Everest), beyond which there is again a decrease as would be expected. The 71″ deflection at Lower Rauje is the largest in the world. This deflection is with respect to the International spheroid. If Everest spheroid had been chosen as the reference surface, it would have been greater.

The section Ladnia-Sarunga-Chautāre-Dungre-Meenashi-Khantel-Rupākot-Aisyālukharka-Pāngu-Khārte-Chaunrikharka-Nāmche Bazār (see

* "Geoid elevation due to masses of Himālayas & Tibet", by Mader. Gerl. Beit. 1936 Volume 46.

DEVIATION OF THE VERTICAL

Scale 1 : 1,000,000.

CHART IV

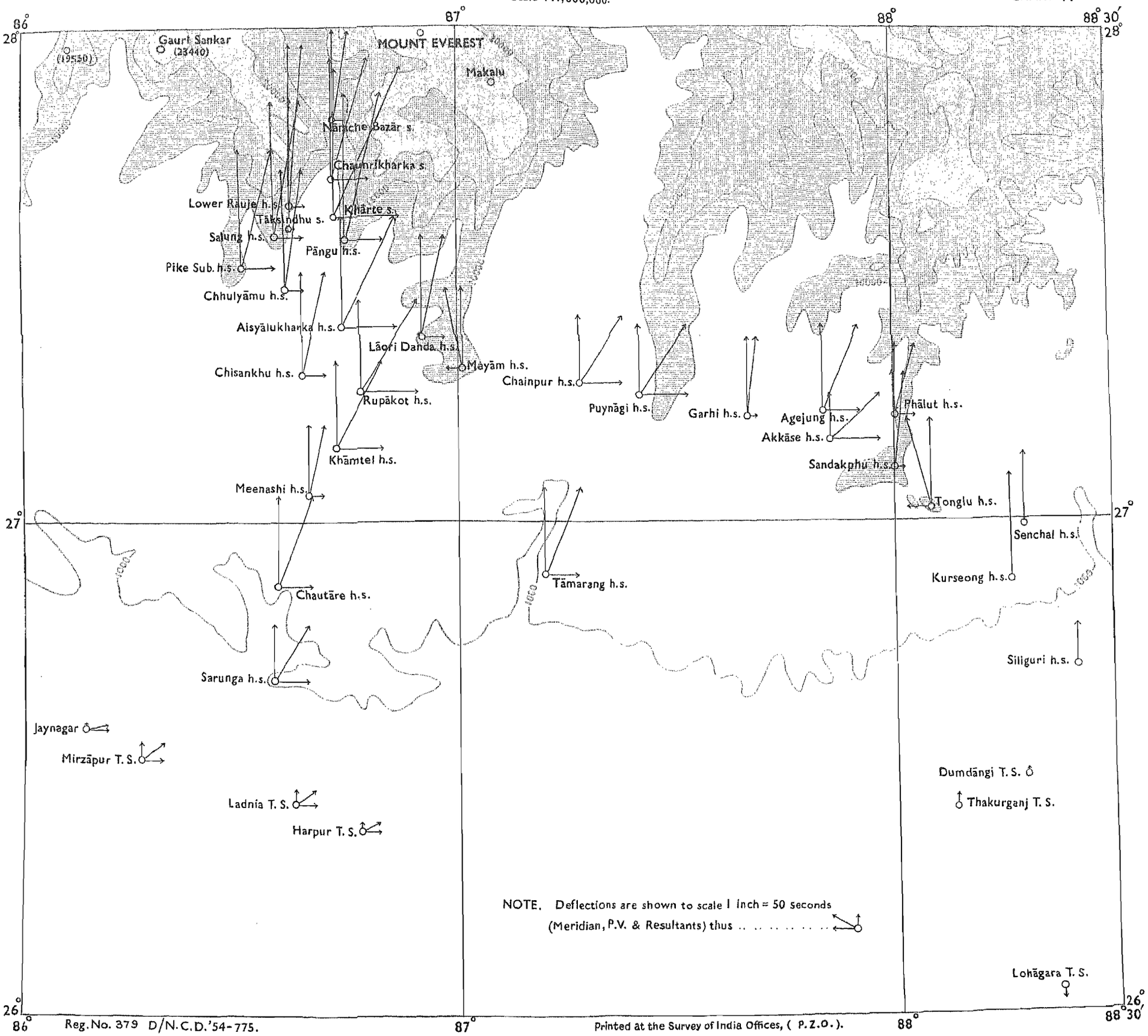

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Chart II) is about 100 miles long and the average interval between stations in its hilly portion is 10 to 12 miles. It is not strictly along a meridian, although very nearly so.

The geoidal rise along this section was carefully computed as follows: Although the curves of observed deflections were fairly smooth, our past experience shows that 10 miles is too long an interval for mountainous regions and that it is desirable in such cases to reduce the station interval by deriving deflections at some intervening stations from theoretical considerations. The Hayford deflection anomalies ($\eta - \eta_c$, $\xi - \xi_c$) were computed for the above stations on the assumption of depth of compensation of 113·7 kilometres and are shown in Fig. 1 along with the curves of observed deflections. As expected, the anomaly curves are much smoother than the (η, ξ) curves. Deflection anomalies at 6 intervening stations (K. 109, K. 108, Dungre h.s., K. 136, S. 130 and Chattarpu h.s.) were read from these curves and Hayford deflections were also computed for them from which values of η and ξ were derived. The values at these stations have been joined by dotted lines and it will be seen that these values produce greater sinuosity in the deflection curves, but they reduce the interval between the stations to an average of 6 miles, and it is hoped that their introduction has helped to eliminate, to a great extent, the systematic errors in the computations of the geoidal rise. It should be noted that this device to obtain deflections at intervening stations is not vitiated by the inaccuracy of the maps or by the fact of Hayford's hypothesis not being true to nature.

As has been explained before, a knowledge of the geoid between the plains and the stations from which Mount Everest has been observed is really not indispensable for deriving the height of Mount Everest. The very nature of our method ensures that the trigonometrical heights of our observations would be geoidal heights even though no account was taken of deflection corrections. This depends on the supposition that the deflections vary linearly between neighbouring stations and are not burdened with large random errors. To check this, the difference of height between Upper Rauje and Rupākot was computed by two methods :—

(*a*) utilizing reciprocal observations, dispersing height triangular errors and ignoring deflections altogether ;

(*b*) by correcting observed vertical angles for deflections, computing spheroidal heights and then applying separation between geoid and spheroid to get geoidal heights.

The difference of heights between the two methods is only 2·6 feet in a differential height of 6,237 feet which is very satisfactory and shows that the deflections are adequately linear. Part of the difference is accounted for by the fact that (*b*) was computed along one flank only, while (*a*) was computed by using a series of triangles.

We now come to the important problem of estimating the anomalous geoidal rise between the observation stations and Mount Everest.

A reference to Fig. 1 shows that the meridional anomaly $\eta - \eta_c$ has nearly a constant value of 16″ in the hilly area from Chautāre to Khārte and dwindles down to zero at Nāmche Bazār. This is in accord with what one would expect. Theory shows that for a depth of compensation of 113·7 kms., the effect of compensation on the deflection should be practically nil for distances up to 18 miles from the peak and the observed deflection should be nearly equal to the topographical deflection. At a distance of

40 miles from the peak, effect of compensation is very material and is of course dependent on the type of compensation assumed. Since η is greater than η_c, we see that the region is under-compensated, a fact which is corroborated by the gravity data.

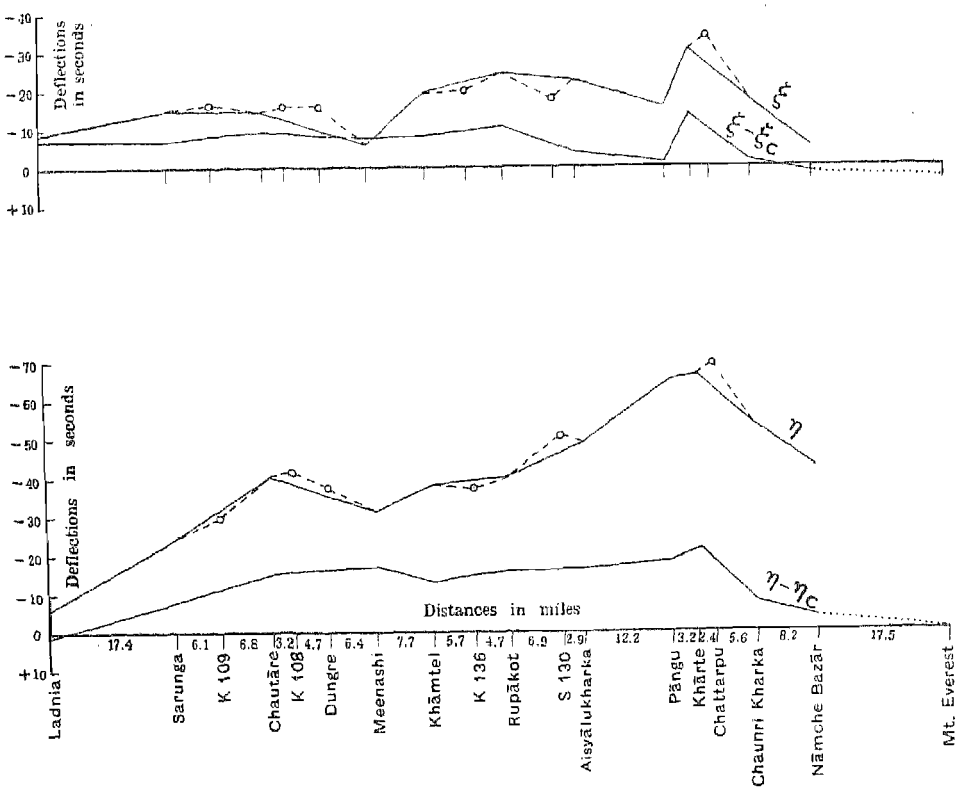
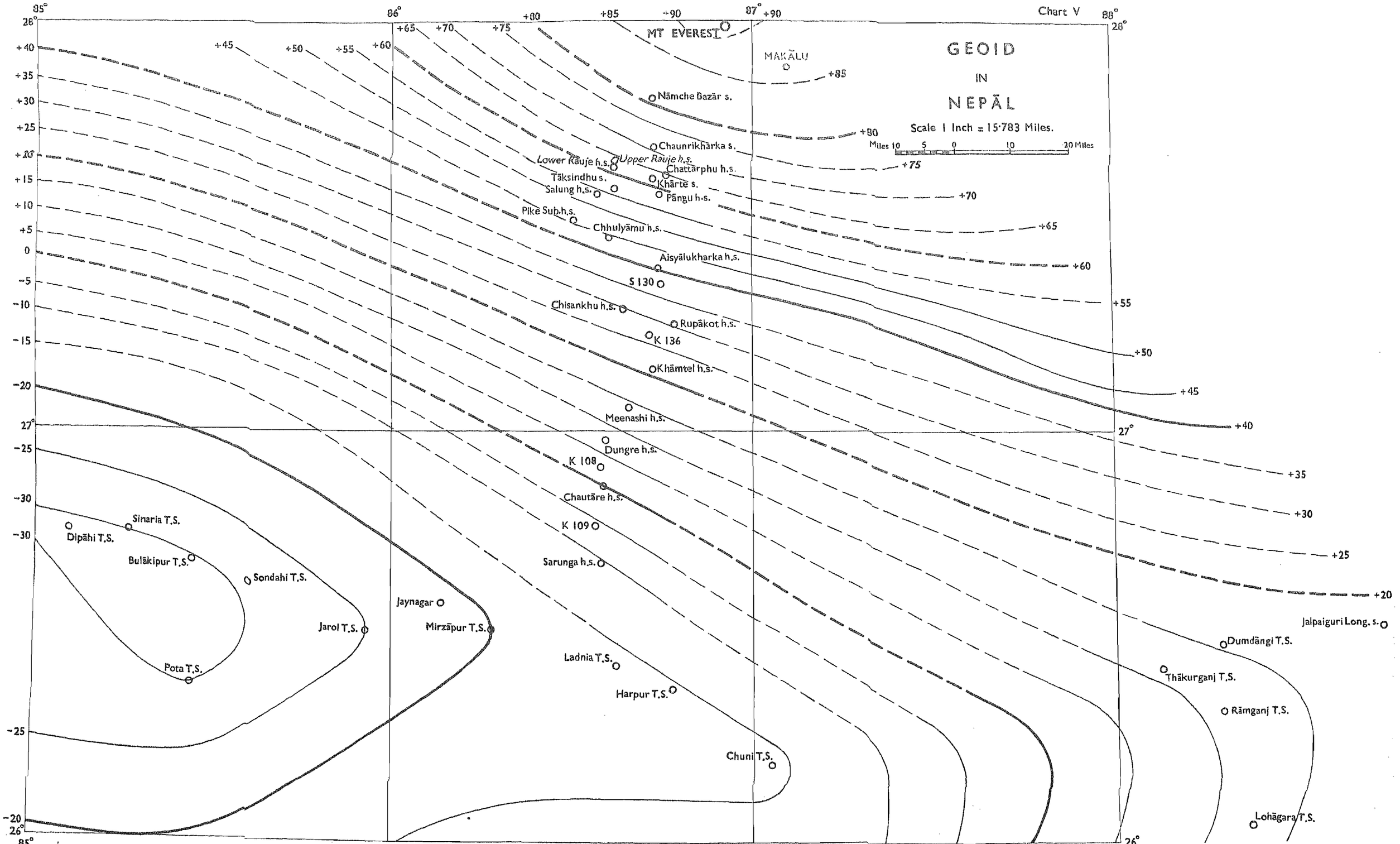


Fig. 1. Deflection and Deflection Anomalies.

The extrapolation of the $(\eta - \eta_c)$ and $(\xi - \xi_c)$ curves up to Mount Everest can, thus, be carried out with a considerable measure of certainty. The extrapolated curve is shown by dotted lines and the values of $\eta - \eta_c$, $\xi - \xi_c$ for Mount Everest are $(+1''\cdot 2, +1''\cdot 9)$. By computations, the Hayford deflections at Mount Everest are $(-13'', -2'')$ from which the deflections derived are $(-11''\cdot 8, -0''\cdot 1)$. These can be utilized for computing the geoidal height of Mount Everest. An independent method is to integrate $\eta - \eta_c$ and $\xi - \xi_c$ between Nāmche Bazār and Mount Everest and to this value add the rise of the isostatic geoid as derived from considerations of topography. The final value arrived at for the geoidal height of Mount Everest by a consideration of the two methods is 92·3 feet.

Table 3 gives the deflections at stations which have been utilized to draw a picture of the geoid in this area. The meridional components of the deflection have been corrected for the normal curvature of the vertical. The resulting geoid is shown in Chart V and is believed to be of a high order of accuracy. The deflection stations have been chosen at stations



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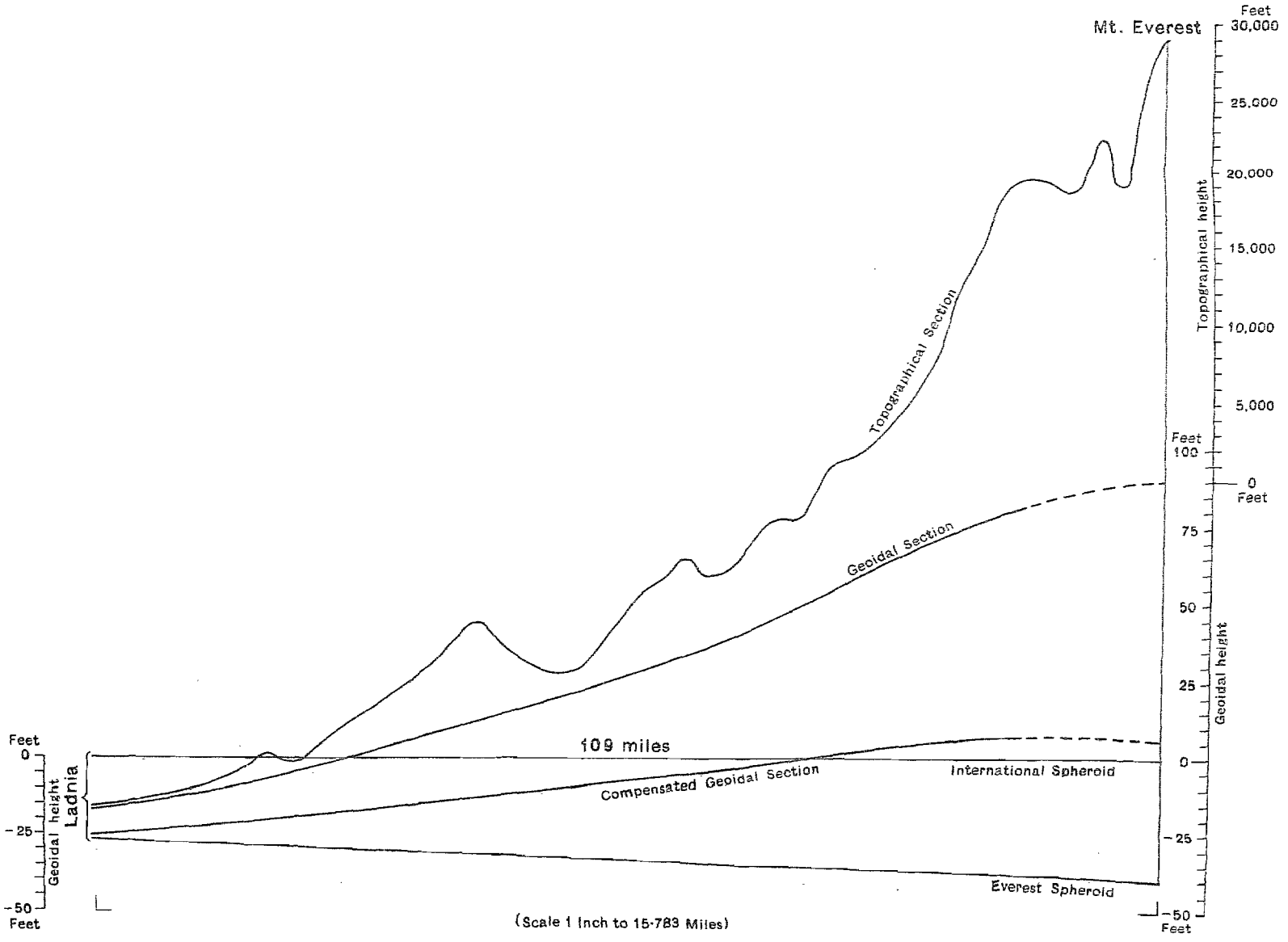
GEOIDAL SECTION

LADNIA — MT EVEREST

Chart VI



Reg. No. 380D/N. C.' 54 (G. & R. B.)-625.

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of topographical triangulation and these can be regarded as unlikely to be in error by more than $\pm 0''\cdot 1$. The probable error of the astronomical latitudes is $\pm 0''\cdot 3$. The average interval between the stations is 6 miles and the probable error of the geoidal rise N in so far as it depends on the meridional components of the deflections can be reckoned to be $\pm 0\cdot 3$ feet. The error of personal equation in the oblique portion of the section may produce an error of a foot or so and so might the neglect of the rigid curvature correction to meridional deflections. The last lap between Nāmche Bazār and Mount Everest may further be in error by $\pm \frac{1}{2}$ foot. The total probable error of the geoid in the Mount Everest region can, thus, be reckoned to be of the order of 2 feet.

Chart VI showing the section along the line of greatest change from Ladnia in the plains of Bihār to Mount Everest is unique and of very great interest. The geoid shows an unprecedented rise of 109 feet in a distance of 109 miles.

Computations show that the topographic geoid due to visible masses would produce a rise of 333 feet. The actual geoid displays 1/3rd of this rise indicating a considerable measure of compensation. To get an idea of the magnitude of the compensation, Hayford deflections were computed for these stations and Hayford anomalies were integrated for the section. The corresponding geoidal rise of the compensated geoid between the two points is 31 feet.

Both, the natural and compensated geoids follow the topography and in the higher hills there are indications of a certain amount of under-compensation. Gravity observations have also been taken in this region and confirm the above conclusion.

8. **Final Value of Height.**—Vertical angle observations to Mount Everest were observed with a Tavistock theodolite in 1952–53 and with a Geodetic Wild theodolite in 1953–54. An abstract is given in Table 4. A number of sets were taken at each station. They were generally very consistent and the mean of the various sets on each day was used for calculating the height. Column 6 shows the number of sets from which it would appear that a sufficiently large number of observations spread over three months in two different years have been taken to get a reliable value of height. As a rule, at these heights, diurnal variation of refraction is very small and it is not essential to adhere strictly to the time of minimum refraction. However, column 3 will show that in the main, observations have been taken at this time. With the data derived in the previous paragraphs, the ground is now cleared for arriving at the final value of height of Mount Everest.

The geoidal heights as derived from each station are given in Table 5. The various columns in this table are self-explanatory. Column 5 gives the spheroidal height difference between the station of observation and Mount Everest and column 7 the corresponding geoidal rise.

The heights, as tabulated in the last column, are burdened with the following errors :—

(*a*) Error in adopted geoidal height of observing stations. These are well tied to spirit-levelled heights and can be in error by 2 or 3 feet at the most.

(*b*) Errors in δN the estimated geoidal rise between the stations and Mount Everest. This can attain a maximum of 5 feet but should be better than this.

(*c*) Errors due to estimated refraction.

No observational data for lapse rate exists for the actual stations and the refraction is computed on the hypothesis of saturated adiabatic lapse rate of 3·2°F/1,000 feet. For each ray, the coefficient of refraction is computed with this lapse rate for temperature and pressure appropriate to a point one-third the distance along the line. The variations in the lapse rate have, however, an important effect on the refraction. A reference to the normal charts of the Meteorological Department shows that the average lapse rate in the Mount Everest region agrees very well with the above value. The vertical angle observations were taken during the months of December to March on sunny days when there was no possibility of inversion. Variation can occur in this lapse rate due to changing pressure and other abnormal conditions, but it is believed that the deviations from this adopted lapse rate are never likely to be more than 20% in our case as the observations were carried out at the time of minimum refraction and the lines were well clear of grazes. A fluctuation of this amount in the lapse rate would introduce an error of only 3% in the adopted value of k, which would produce an error of 1 foot or so in height over a ray of 35 miles length. The error due to refraction may be considered as random for different stations and of very small amount. Considering that we have observations from eight stations, spread over a period of three months in two years, the effect of refraction errors on the mean value should be quite negligible.

A perusal of column (8) shows that the scatter of the derived values is only 16 feet, which is very satisfactory and is compatible with the above remarks regarding the errors due to different sources. In deriving the final result, weights have to be assigned to the values from the various stations taking into account the total number of observations, the number of days on which observations have been made and the length of the rays. It might, however, be pointed out that repeat observations on the same day are heavily correlated and even the observations on consecutive days are correlated to some extent. For instance, it can happen that successive observations on four days made during the time of minimum refraction may contain the same systematic error. These observations can, thus, be regarded as a general check against gross errors in the vertical angles accepted for computation.

As regards the length of the rays it is still open to doubt whether the weights should be assigned proportional to reciprocal of the length of the ray or the reciprocal of the square of the length of the ray. Fortunately the scatter of the observations is such that it does not make much of a difference whichever form of weighting is adopted.

The weighted mean value of the height of Mount Everest workout to be 29,028 feet with a probable error of ± 0·8 feet. This probable error is derived from internal evidence alone and is likely to be too small on account of the presence of systematic errors. Bearing in mind the various possible sources of error, it is considered that the odds are 20 to 1 against this value being in error by more than 10 feet.

The height has been determined during the months of December to March. This is the period when the amount of snow on the top is likely to be least as the north-west wind is in its full stride. There is heavy precipitation of snow during the monsoon months—June to September—and, although there is no observational evidence available regarding the change of snow fall at the summit, it is likely to be well over 10 feet.

It might be of interest to record here that Makālu which rises from the main snowy range at a distance of 12 miles to the east of Mount

Everest has also been re-observed for height. From the Darjeeling hills, this peak dominates the landscape rather than Mount Everest because it is about 12 miles nearer.

It is supposed to be the fifth highest in the world and has been very much in the news lately, as an American Expedition made a bid to conquer it in 1954 for the first time but had to turn back due to bad weather and difficult terrain.

Makālu was observed in 1849–50 from six low lying stations in the plains, at distances of about 110 miles from it. Like Mount Everest, its height was also computed with a faulty value of the coefficient of refraction and without proper considerations of datum and deflection of the plumb-line and the value adopted was 27,790 feet. In 1952–53, observations were taken to this peak from five stations at distances varying from 35 to 80 miles. The value resulting from these observations after taking due count of the geoid under Makālu is 27,824 feet. This is the value which will be adopted for the future.

It might be noted that although the present observations enable the height of Mount Everest to be determined with a high degree of precision, they do not contribute to the question of the uplift of the Himālayas. The question of the amount of erosion at the top of such high hills and the secondary rise to achieve isostasy must still remain a matter of speculation. Although the rock summit is subject to violent seasonal winds, it is never bare of snow and the erosion is not likely to be considerable.

9. **Analysis of the older values of 29,002 feet and 29,141 feet for Mount Everest.**—The above two figures are so well known that to avoid future misunderstandings regarding them, it is worthwhile putting down their exact significance. 29,002 feet is a vague height determined from earlier computations of 1850 or so which can be reckoned to be either as being above the geoid or above the Everest spheroid so oriented as to be tangential to the geoid in the plains south of Nepāl. The datum surface was ignored during its derivation and the coefficient of refraction used was faulty. The reasons why it agrees so closely with the new value is due to a lucky cancellation of errors as the following will show.

Error in the assumed heights of the observing stations raised the height by 8 feet; the neglect of plumb-line deflections made the height lower by about 30 feet. Neglect of geoidal rise between the plains of Bihār and Mount Everest raised the height by 115 feet or so and taking an excessively large coefficient of refraction made the height lower by about 120 feet. If the last two sources of error had conspired in the same direction, the derived height would have been in error by over 200 feet. It will be seen that two sources of error made the heights lower and two higher, resulting in a lucky cancellation of errors.

Of much greater interest is the reason why Burrard, who was equipped with much better information, went astray by a much greater amount in his conclusions. He was one of the most famous geodesists of his time and did a lot of work on the determination of heights of lofty peaks.

In his Himālayan Geography*, he gives an account of how in 1905 he derived the value 29,141 feet for the height of Mount Everest by utilizing the later observations of 1880 as well. He was able to effect one

* "A sketch of the Geography and Geology of the Himālaya Mountains and Tibet" by Burrard, Hayden & Heron (1933), pp. 56–57.

important improvement in that he could make use of the latest knowledge on refraction. He was convinced, and it has often been stated in several publications, that his figure of 29,141 feet was much more accurate than 29,002 feet. On page 57, Burrard comments that although this figure is by no means final, "The height 29,141 feet is still probably too small, as it has yet to be corrected for the effects of deviations of gravity". He discusses this question again in detail* in a later paper, and points out the difficulty of finding a base for height measurement of the Himālayan snow peaks. Burrard makes a fundamental and a persistent error of principle in his arguments regarding choice of datum. He visualized the possibility of abnormal deformation of sea-level by as much as 300 feet under Tibet, but contended that this had no bearing on the question of the heights of peaks and that the spheroidal heights were all that would be of interest to the geographers. In view of the remarks in para 7, it would be apparent that this is not correct. The estimation of geoidal rise between the stations of observation and Mount Everest involves an extra step but it has to be done.

Actually, Burrard's figure of 29,141 feet is even more vague than the earlier determination. Although, refraction has been treated more rationally, his values derived from stations in the plains are on an Everest spheroid, while these derived from hill stations are above different Everest spheroids tangential to the geoid at those stations.

He visualized correctly that the application of deflections would increase his figure of 29,141 feet, and recent observations show that this increase would be only 30 feet. The consideration of the geoidal rise, however, which he ignored necessitates a diminution of over a 100 feet, so that on the whole the above figure would be decreased.

10. **Summary.**—The newly determined height of Mount Everest is 29,028 feet. It is but timely that the challenge of its height determination should have been met shortly after its actual conquest. This is the first time that the height of an important inaccessible peak has been determined by a rigorous technique involving a relatively complicated nexus of facts and ideas. Geodetic observations had to be carried close to the peak to get quantitative figures for the distortion of the mean sea-level and the tilt of the vertical produced by the colossus.

The new determination stands in a class by itself and its close agreement with the older value does not signify that the latter was well determined. It is really due to the fact that like is not being compared with like. Judged by modern standards, the earlier deduction of the height of Mount Everest was vague in several respects, and was burdened with large errors on account of neglect or incomplete consideration of certain physical factors. It so happened that by chance, the various individual errors, although large, have tended to cancel each other.

There are several outstanding peaks in the Himālayan range —K^2, Kānchenjunga, Nanga Parbat, Dhaulāgiri, etc.—which also need treatment similar to that in this paper. Doubt still remains whether K^2 or Kānchenjunga should occupy the next place. Their accepted heights are 28,250 feet and 28,146 feet respectively and the difference is well within the errors of older determination. Some recent observations have been taken to Kānchenjunga and preliminary computations show that its adopted height needs increasing by 60 feet or so.

* "The Place of Mount Everest in History" by Col. Sir S. G. Burrard. Empire Survey Review, September 1934, p. 456.

TABLE 1.—*Height of Mount Everest from observations from the plains*

Observing station		Height of observing station in feet	Distance of observing station from the peak in miles	Date of observation	Observer	Instrument	No. of observations	Observed angle of elevation	Height in feet above Mean sea-level	Coefficient of refraction	Direction of the peak from the observing station	Astronomical time of observation
								° ′ ″				h m h m
Jirol	T.S.	231	118·661	Nov. 27, 1849	Mr. J. O. Nicholson	24-Inch Theodolite	2	1 53 33·35	28,991·6	·073525	NE.	3 40
Mirzāpur	T.S.	254	108·876	Dec. 5 & 6, 1849			12	2 11 16·66	29,005·3	·073651	N.	2 36, 5 10 4 32
Janjipati	T.S.	263	108·262	Dec. 8 & 9, 1849			4	2 12 09·31	29,001·8	·073150	N.	5 26, 5 19
Ladnia	T.S.	242	108·861	Dec. 12, 1849			4	2 11 25·52	28,998·6	·074613	N.	2 53
Harpur	T.S.	226	111·523	Dec. 17 & 18, 1849			8	2 06 24·98	29,026·1	·072655	N.	4 00, 5 33
Minai	T.S.	237	113·761	Jan. 17, 1850			8	2 02 16·61	28,990·4	·075272	N.	2 55, 3 38
									Mean 29,002·3			

TABLE 2.—*Height of Mount Everest from observations from Darjeeling Hills*

Observing station		Height of observing station in feet	Distance of observing station from the peak in miles	Date of observation	Observer	Instrument	No. of observations	Observed angle of elevation	Height in feet above Mean sea-level	Coefficien of refraction	Direction of the peak from the observing station	Astronomical time of observation
								° ′ ″				
Suberkum	h.s.	11641	87·636	Oct. 4, 1881	Capt. Harman	T. & S. 6″	2	1 35 13	29141	·0463	NW.	Early in the morning
Tiger Hill	h.s.	8507	107·952	May 30, 1880		T. & S. 12″ No. 11	6	1 21 44	29140	·0471	,,	Not mentioned
								Mean	29141			
Suberkum	h.s.	11641	87·636	May 16 & 26, 1883	Col. Tanner	T. & S. 12″ No. 11	6	1 35 11	29137	·0463	,,	,,
Sandakphu	h.s.	11929	89·666	May 28, 1883		,,	1	1 29 21	29142	·0457	,,	,,
								Mean	29140			
Phalut	h.s.	11816	85·553	March 16, 1902	Lt. Cowie	T. & S. 12″	6	1 37 50·2	29151	·0450	,,	,,
Senchal	h.s.	8599	108·703	Feb. 23, 1902		,,	2	1 20 23·4	29134	·0513	,,	,,
								Mean	29143			
								General Mean	29141			

TABLE 3.—*Deflections and Hayford Anomalies*

Serial No.	Sheet No.	Station	Height in feet	Latitude	Longitude	Deflections* on International spheroid: Meridional η	Deflections* on International spheroid: P.V. ξ	Hayford Anomalies Depth of compensation —113·7 kms.: Meridional $\eta-\eta_c$	Hayford Anomalies Depth of compensation —113·7 kms.: P.V. $\xi-\xi_c$
				° ′ ″	° ′ ″	″	″	″	″
1	72 F	Bulākipur T.S.	223	A 26 40 51·69 G 26 40 55·73	A 85 26 20·43 G 85 26 31·01	— 0·3	— 1·5	+ 6·0	+ 0·4
2	,,	Sondahi T.S.	201	A 26 37 36·35 G 26 37 43·27	A 85 35 34·90 G 85 35 51·85	— 0·4	— 7·1	..	..
3	,,	Jarol T.S.	193	A 26 30 50·10 G 26 30 55·00	A 85 55 12·77 G 85 55 32·11	— 1·4	— 9·1	..	..
4	72 J	Mirzāpur T.S.	219	A 26 30 51·00 G 26 31 02·15	A 86 16 19·06 G 86 16 38·09	— 7·7	— 8·6	— 0·6	— 6·8
5	,,	Ladnia T.S.	208	A 26 25 40·73 G 26 25 50·32	A 86 36 56·06 G 86 37 15·04	— 6·2	— 8·5	+ 1·3	— 7·2
6	,,	Harpur T.S.	199	A 26 22 17·74 G 26 22 25·23	A 86 46 14·42 G 86 46 31·92	— 4·1	— 7·1	..	..
7	,,	Sarunga h.s.	1289	A 26 40 22·05 G 26 40 50·21	A 86 34 15·84 G 86 34 41·59	— 24·7	— 14·4	— 8·0	— 6·4
8	,,	K. 109	568 (Top)	A .. .. G 26 46 08·99	A .. .. G 86 34 11·55	— 29·3	— 15·9	— 11·7	— 8·0
9	,,	Chautāre h.s.	2615	A 26 51 17·04 G 26 52 00·93	A 86 34 59·43 G 86 35 25·17	— 40·3	— 14·3	— 15·0	— 9·4
10	,,	K. 108	3714	A .. .. G 26 54 46·79	A .. .. G 86 35 02·77	— 41·3	— 15·6	— 15·5	— 8·9
11	,,	Dungre h.s.	6953	A .. .. G 26 58 44·96	A .. .. G 86 35 58·22	— 37·7	— 15·6	— 16·2	— 8·2
12	72 I	Meenashi h.s.	6318	A 27 02 44·60 G 27 03 19·66	A 86 39 17·19 G 86 39 33·68	— 31·4	— 6·0	— 17·1	— 7·7
13	,,	Khāmtel h.s.	4373	A 27 08 19·86 G 27 09 01·95	A 86 43 03·44 G 86 43 34·77	— 38·4	— 19·2	— 13·2	— 8·2

(*contd.*)

* The meridional components of deflection have been corrected for normal curvature of the vertical.

Note :—Values in bold type indicate that astronomical observations were not taken at these stations.

TABLE 3.—*Deflections and Hayford Anomalies*—(contd.)

Serial No.	Sheet No.	Station	Height in feet	Latitude	Longitude	Deflections* on International spheriod: Meridional η	Deflections* on International spheriod: P.V. ξ	Hayford Anomalies Depth of compensation —113·7 kms.: Meridional $\eta-\eta_c$	Hayford Anomalies Depth of compensation —113·7 kms.: P.V. $\xi-\xi_c$
				° ′ ″	° ′ ″	″	″		
14	72 I	K. 136	6847 (Top)	A .. G 27 13 55·67	A .. G 86 42 58·26	**— 37·6**	**— 19·7**	— 14·8	— 9·5
15	,,	Rupākot h.s.	8525	A 27 14 57·07 G 27 15 41·26	A 86 46 30·06 G 86 47 07·15	— 40·5	— 24·2	— 15·9	— 10·3
16	,,	S. 130	6972	A .. G 27 21 21·10	A .. G 86 44 58·79	**— 50·4**	**— 17·5**	— 16·1	— 5·6
17	,,	Aisyālukharka h.s.	8670	A 27 22 56·36 G 27 23 48·93	A 86 43 57·68 G 86 44 32·44	— 48·9	— 22·1	— 16·4	— 3·4
18	,,	Chisankhu h.s.	5020	A 27 16 58·71 G 27 17 48·66	A 86 38 18·56 G 86 38 40·52	— 46·1	— 10·9	..	..
19	,,	Chhulyāmu h.s.	10160	A 27 27 09·83 G 27 28 06·94	A 86 36 20·21 G 86 36 37·43	— 53·3	— 6·7	— 13·3	— 6·0
20	,,	Pike Sub. h.s.	12059	A 27 29 58·88 G 27 30 54·77	A 86 30 09·77 G 86 30 34·33	— 52·1	— 13·2	— 15·0	— 5·0
21	,,	Sollung h.s.	11658	A 27 33 33·89 G 27 34 37·61	A 86 34 08·75 G 86 34 30·59	— 59·9	— 10·8	— 16·9	— 5·8
22	,,	Lower Rauje h.s.	13357	A 27 37 18·38 G 27 38 33·38	A 86 37 03·75 G 86 37 18·63	— 71·1	— 4·5	— 16·0	— 2·8
23	,,	Upper Rauje h.s.	14762	A 27 38 22·35 G 27 39 33·60	A 86 37 21·06 G 86 37 33·50	— 67·4	— 2·2	— 14·2	+ 3·8
24	,,	Pāngu h.s.	11231	A 27 33 15·24 G 27 34 23·96	A 86 44 29·73 G 86 44 56·91	— 64·9	— 15·3	— 18·1	— 0·7
25	,,	Khārte resected station	8637	A 27 35 43·70 G 27 36 53·7	A 86 42 49·10 G 86 43 32·7	— 66·1	— 29·9	— 21·5	— 12·9
26	,,	Chattarpu h.s.	14801	A .. G 27 37 22·93	A .. G 86 45 51·95	**— 69·0**	**— 33·0**	— 17·5	— 9·5

* The meridional components of deflection have been corrected for normal curvature of the vertical.

Note.—Values in bold type indicate that astronomical observations were not taken at these stations.

contd.

TABLE 3.—*Deflections and Hayford Anomalies*—(concld.)

Serial No.	Sheet No.	Station	Height in feet	Latitude	Longitude	Deflections* on International spheroid: Meridional η	Deflections* on International spheroid: P.V. ξ	Hayford Anomalies Depth of compensation —113·7 kms.: Meridional $\eta-\eta_c$	Hayford Anomalies Depth of compensation —113·7 kms.: P.V. $\xi-\xi_c$
				° ′ ″	° ′ ″	″	″	″	″
27	72 I	Chaunrikharka resected station ..	8806	A 27 40 41·03 G 27 41 38·3	A 86 42 44·79 G 86 43 13·6	− 53·4	− 16·8	− 7·5	− 1·3
28	,,	Nāmche Bazār resected station ..	12713	A 27 48 00·12 G 27 48 46·5	A 86 42 56·33 G 86 43 12·0	− 42·5	− 5·2	− 3·6	+ 2·2
29	,,	Mt. Everest	29028	A .. G 27 59 15·85	A .. G 86 55 39·51	− 13·0	+ 1·0	0	+ 3·0
30	,,	Lāori Danda h.s.	11877	A 27 21 30·56 G 27 22 19·49	A 86 55 00·46 G 86 55 20·44	− 45·1	− 8·9	− 12·9	− 13·6
31	72 M	Mayām h.s.	10948	A 27 18 01·98 G 27 18 41·38	A 87 00 51·34 G 87 00 52·53	− 35·7	+ 7·8	− 9·4	+ 1·0
32	,,	Chainpur h.s.	5016	A 27 15 58·20 G 27 16 31·83	A 87 16 18·89 G 87 16 50·85	− 29·9	− 19·4	..	..
33	,,	Puynagi h.s.	9112	A 27 14 51·87 G 27 15 26·93	A 87 24 54·84 G 87 25 27·83	− 31·3	− 20·2	..	..
34	,,	Garhi h.s.	7303	A 27 12 10·33 G 27 12 49·18	A 87 39 42·92 G 87 39 56·85	− 35·2	− 3·2	..	..
35	,,	Agejung h.s.	8068	A 27 12 41·40 G 27 13 23·32	A 87 49 46·41 G 87 50 15·81	− 38·2	− 16·5	..	..
36	,,	Akkase h.s.	7063	A 27 09 25·59 G 27 09 49·89	A 87 50 33·99 G 87 51 09·86	− 20·6	− 22·2	..	..
37	78 A	Phalut h.s.	11798	A 27 12 07·12 G 27 12 41·82	A 88 00 39·89 G 88 01 00·03	− 31·1	− 9·0	..	..
38	,,	Sandakphu h.s.	11915	A 27 05 25·20 G 27 06 11·62	A 87 59 45·98 G 88 00 02·10	− 42·8	− 4·7	..	..
39	,,	Tonglu h.s.	10057	A 27 01 10·75 G 27 01 53·54	A 88 05 03·96 G 88 05 02·90	− 39·2	+ 11·2	..	..

* The meridional components of deflection have been corrected for normal curvature of the vertical.

Note.—Values in bold type indicate that astronomical observations were not taken at these stations.

TABLE 4.—*Vertical angles to Mount Everest*

Station		Date	Time	Pressure	Temperature	No. of sets	Observed vertical angle	Deflection correction on International spheroid
(*Season* : *1952–53*)								
			h m	"	F°		° ′ ″	"
Mayām	h.s.	31–3–1953	12 13 to 12 22	20·09	58·8	5	3 52 19·7	+36·46
Lāori Danda	h.s.	26–3–1953	12 01 to 12 33	19·49	55·2	5	4 05 59·38	+45·17
,,	,,	27–3–1953	12 08	19·29	60·3	1	4 06 00·65	+45·17
,,	,,	28–3–1953	12 08 to 12 26	19·40	55·5	4	4 06 03·96	+45·17
,,	,,	29–3–1953	12 07 to 12 17	19·30	56·3	5	4 05 58·54	+45·17
Aisyālukharka	h.s.	3–2–1953	12 29 to 15 31	22·11	45·0	26	4 56 17·71	+53·22
,,	,,	9–2–1953	12 27 to 15 05	22·07	51·0	22	4 56 13·72	+53·22
,,	,,	10–2–1953	12 01 to 13 24	22·11	52·3	23	4 56 16·01	+53·22
Chhulyāmu	h.s.	16–2–1953	14 39 to 15 09	20·76	57·9	10	4 44 53·50	+50·74
,,	,,	19–2–1953	12 00 to 15 01	20·73	58·2	45	4 44 56·98	+50·74
,,	,,	20–2–1953	11 50 to 13 24	20·87	54·1	29	4 44 57·57	+50·74
Piko Sub.	h.s.	24–12–1952	12 02 to 15 30	19·90	37·8	60	4 09 39·8	+49·69
,,	,,	29–12–1952	12 01 to 15 23	19·48	37·8	47	4 09 46·9	+49·69
,,	,,	30–12–1952	12 04 to 14 45	19·53	33·9	37	4 09 48·6	+49·69
Sollung	h.s.	3–1–1953	12 18 to 15 48	19·62	36·1	50	5 02 44·3	+54·81
,,	,,	4–1–1953	12 25 to 15 07	19·68	40·9	28	5 02 37·9	+54·81
,,	,,	5–1–1953	12 36 to 14 13	19·74	46·6	6	5 02 37·0	+54·81
Lower Rauje	h.s.	10–1–1953	12 09 to 14 01	18·31	40·9	27	5 23 35·4	+58·99
Upper Rauje	h.s.	26–2–1953	11 41 to 15 04	17·56	43·0	56	5 05 02·45	+54·83
,,	,,	27–2–1953	10 58 to 15 01	17·46	49·1	56	5 05 01·20	+54·83
,,	,,	28–2–1953	11 31 to 12 35	17·53	41·6	19	5 05 02·88	+54·83
(*Season* : *1953–54*)								
Chhulyāmu	h.s.	2–12–1953	9 53 to 10 13	21·14	50·1	6	4 45 01·0	+50·74
Piko Sub.	h.s.	5–12–1953	13 56 to 15 20	19·70	51·0	2	4 09 42·4	+49·69
Sollung	h.s.	11–12–1953	12 26 to 15 32	20·13	40·2	8	5 02 41·4	+54·81
Upper Rauje	h.s.	16–12–1953	14 24 to 14 31	17·88	36·1	3	5 05 03·47	+54·83

TABLE 5.—*Height of Mount Everest*

Station (1)	Season (2)	Distance (3)	Height of station (4)	Spheroidal height difference (5)	Sum (6)	δN = Geoidal rise between the station and Mount Everest (7)	Geoidal height of Mount Everest = (6)−(7) (8)
		miles	feet	feet	feet	feet	feet
Mayām ..	1952–53	47	10948·1	18145·6	29093·7	55	29038·7
Lāori Danda ..	1952–53	42	11877·4	17206·2	29083·6	51	32·6
Aisyālukharka..	1952–53	42	8670·3	20412·7	29083·0	52	31·0
Chhulyāmu ..	1952–53	41	10160·4	18920·1	29080·5	50	30·5
Pike Sub. ..	1952–53	41	12059·3	17011·8	29071·1	47	24·1
Sollung ..	1952–53	36	11657·9	17411·4	29069·3	40	29·3
Lower Rauje ..	1952–53	30	13357·4	15700·8	29058·2	32	26·2
Upper Rauje ..	1952–53	29	14762·1	14293·1	29055·2	30	25·2
Sollung ..	1953–54	36	11657·9	17409·9	29067·8	40	27·8
Pike Sub. ..	1953–54	41	12059·3	17015·3	29074·6	47	27·6
Upper Rauje ..	1953–54	29	14762·1	14290·7	29052·8	30	22·8
Chhulyāmu ..	1953–54	41	10160·4	18917·8	29078·2	50	29028·2

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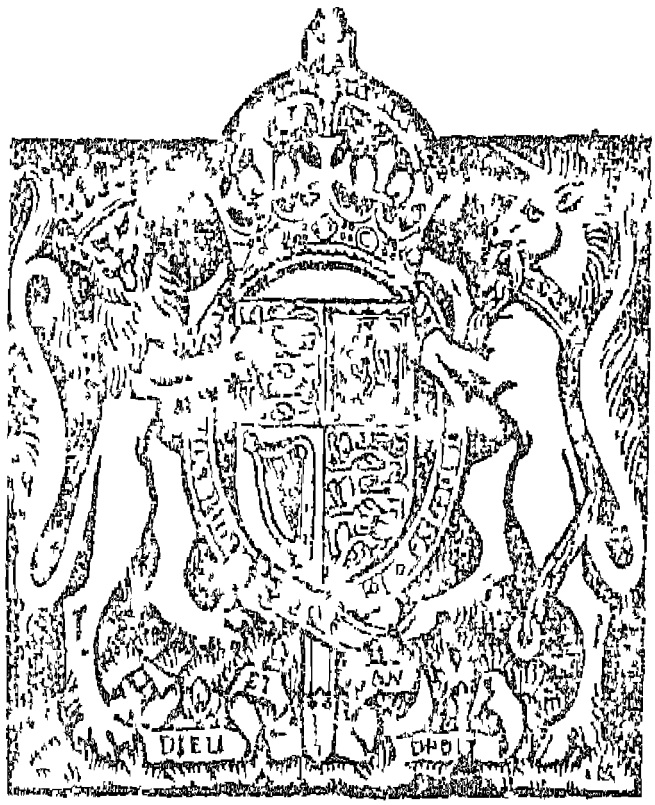

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