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Heights of Himalayan Snow-peaks

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ABSTRACT. Judged by modern standards, the heights of the Himalayan snow-peaks have been determined very unsatisfactorily. In particular, the value 29,002 ft for the height of *Mount Everest* has endured for over a century and there is little realization at the present day of the extent to which it is wrong. The difference of 104 ft in the accepted heights of K^2 and *Kanchenjunga* is less than the probable error in the determination of their heights and it is by no means certain that K^2 rightly enjoys the pride of place as being the second highest peak in the world.

An attempt has been made in this paper to present in non-technical language the outstanding difficulties in the way of height determination of lofty peaks. Some of the data needed for the purpose are still lacking and entail the sending of Geodetic Expeditions to the Himalayan regions. It is pointed out that accurate determination of the heights of snow peaks is only possible by taking new scientifically planned observations from triangulation stations established close to these peaks.

1. General

Snow-peaks have fascinated man since times immemorial. Overwhelmed by their stupendous magnitude and indescribable beauty, ancients have bowed before them in veneration. And even in this age when machinery seems to dominate man and all resources are calculated in terms of mechanical horse-power, the snow-peaks have retained their lure for mountaineers and explorers to scale them on foot.

The mighty expanse of the Himalayas abounds in peaks much higher than those in any other part of the world and one of the problems, which is of absorbing interest to the Surveyor, the Geographer and the Geodesist, is the determination of the heights of these peaks. Unfortunately, not as much attention has been given to this problem as it deserves.

There are several reasons for this. For one thing, to the common man, the heights of peaks are not necessarily an index of their relative importance. Thus Badrinath (*23,190 ft*) and Nanda Devi (*25,645 ft*) are much better known and command much great veneration amongst the plains folk than Nanga Parbat (*26,620 ft*) and Kanchenjunga (*28,146 ft*). And secondly, as will be seen later, the determination of heights of high peaks in the Himalayas, which have some independent sovereign states in their foothold, bristles with several technical and administrative difficulties and the various operations required tend to be costly.

There are many factors to be taken into account in dealing with the problem of the determination of absolute elevations of high mountains. Even the relative heights of peaks, far apart, cannot be adjudged by merely looking at them. When viewed from the plains of Nepal, Mount Everest, in spite of its towering personality, does not appear to overshadow the array of numerous peaks around it. In fact, some of the peaks, on account of their nearness, give the delusion of being higher than it and when observations were taken to Mount Everest, there never was the slightest suspicion that it was the highest mountain in the world.

In the last century, spasmodic efforts were made to get heights of snow-peaks in the course of surveys but beyond some routine computations, not much headway was made to get any reliable results. There was no time and money available for systematic research. The upshot was that generally simple arithmetical means of crudely computed values were adopted, and in some cases the heights derived were based on observations from one station only.

It is not often realised that the observations and computations of the heights of most of the high peaks, in the Himalayas (including Mount Everest), are very weak. Different figures are produced by slightly different manipulation of the observations and some authorities are apt to quote them as concrete evidence of the theory that the Himalayas are rising since the process of mountain formation in this area is believed to be still active.

2. Methods of height determination

There are three methods of determining heights :

(*a*) By a barometer,

(*b*) By trigonometrical observations of the angle of elevation of a point from a station of known height and at a known distance and

(*c*) By spirit-levelling.

Of these, (*c*) is the most accurate one but is not applicable to high peaks as apart from being slow it requires a decent track right up to the summit. An ordinary surveyor normally employs method (*b*) and so long as his work is confined to short rays to hills of moderate height, all is plain sailing. But, when lofty peaks are observed from great distances, numerous complications set in and the problem comes within the domain of higher geodesy, involving a knowledge of advanced theory of refraction, plumb-line deflection, gravity, geoids, datums of reference and so on. In fact, many of the technical considerations defy elucidation in simple language and even the geographers and surveyors find them difficult to comprehend.

Before proceeding further, it would be well to set forth some elementary facts about the various factors that play a significant role in the determination of the heights of very high mountains.

(*i*) *Datums*—In a general way, the term " height " is understood to denote the elevation of a point above mean sea level. To get over the difficulty, that the actual sea may be hundreds of miles away from the peaks whose heights are required, the sea is imagined to be prolonged under the continents by means of narrow channels, providing a level surface of the earth known as the " geoid ". This surface along with the other level surfaces of the earth above it is approximately spheroidal in shape. On account of the irregular distribution of land and sea over the globe, the geoid is necessarily an irregular surface but it has an actual physical existence and the surveyor's or engineer's level at each setting sets itself parallel to it. Under the highest peaks of the Tibetan plateau, the sea level would be raised by more than 1000 ft on account of the attraction of the mighty masses above it. But the Himalayas are known to be underlain by masses of deficient density so that the distortion although very significant will not be so large.

The latitude and longitude which define the position of any point on the surface of the earth are, however, calculated above a geometrical surface called the spheroid. Naturally the best spheroid to use would be the one which approximates most closely to the geoid. While the geoid can be traced in great detail by means of precise levelling from the mean sea level at a coastal observatory, the reference spheroid has a mythical existence and can only be located from the geoid with the help of geodetic observations of gravity and plumb-line deflections.

For various reasons, which need not be gone into here, the heights of Himalayan peaks have to be reckoned above the geoid rather than the spheroid. They then represent the heights of perpendiculars from the peaks to the surface of the water at mean sea level, were this brought from the open sea by channels to points below the peaks. This height is a measure of the effort required by the mountaineer to climb to the summit.

The geodetic programme of plumb-line deflections in late years has enabled determination of the undulations of the geoid with respect to the spheroid to be made sufficiently in detail in the plains. Stations ten to fifteen miles apart along certain lines have sufficed for the purpose. In hilly country, a much closer spacing of 3 to 4 miles is required as deflections change much more rapidly and this has never been done. The separation between the geoid and the spheroid under the high mountains can thus only be conjectured and the derived height can be burdened with significant error due to this reason.

(*ii*) *Plumb-line deflections*—Mountains attract a plumb-line towards them. As mentioned above, the normal to the geoid represents the true vertical and the bubble of any optical instrument when levelled sets itself perpendicular to it. This line generally does not coincide with the normal to the spheroid and the angle between the two verticals is called the deflection of the plumb-line at the station of observation. The method of its determination is a technical problem of geodesy and involves a combination of triangulation and astronomical observations.

Its role in height determinations arises from the fact that the angles observed by theodolites are with respect to the geoid. The liquid in levels of instruments is generally tilted upwards towards high hills and consequently the observed angles of elevation are too small. Observations have thus to be corrected for this tilt, which does not normally worry the surveyor in his ordinary work. It is only in mountainous area that the deflections assume large proportions and have to be taken into account.

Actually there are very few stations from which peaks have been observed, at which deflection data are available. In certain cases, the error in height due to neglect of deflections may well be over 50 feet.

(*iii*) *Refraction*— By far the most baffling problem, in the calculation of heights from vertical angles, has been that of refraction. An observer, viewing a peak B from a point A, does not see it along the straight line AB but along a curved line. The point B appears to him elevated along the tangent to the curve. This is due to the fact that light passing through air whose density varies with height is curved in a vertical plane. A correction has, therefore, to be applied to observed angles on account of refraction, but its exact evaluation presents great difficulties.

The reason is, that refraction depends on temperature, pressure and temperature gradient of the atmospheric layers through which a ray passes and is consequently changing all the time. In the olden days, reciprocal vertical angles were taken and it was thought that refraction was the same at both ends of the ray and cancelled out in the mean. Later on, refraction was estimated by assuming that for all rays starting from a given point, the angle of refraction bears a constant ratio to the angle subtended by the ray at the centre of the earth. This ratio has been termed the " Coefficient of refraction " and a normal value of ·07 or ·05 was assumed for it according as the ray was in the plains or in the mountains. Experience has shown that the above assumptions were untrue both in flat terrain where the rays graze the ground and also for long steep rays. In the latter case, the two ends of the ray are at very different elevations and obviously the refraction at the upper extremity will be much less than at the lower.

By far, the greater portion of the variation of refraction is caused by the temperature gradient which is subject to large fluctuations in the course of a day and in particular near the vicinity of the ground.

It can be established from thermodynamical principles that the greatest stable lapse rate that can occur in the free atmosphere is the dry adiabatic gradient amounting to 5·42°F per 1000 feet. On a clear calm day this condition of adiabatic equilibrium is likely to be achieved in free air by the agency of convection currents. But normally the fall of temperature with height is not so great as this and 3°F per 1000 ft is a more representative value.

Modern tables of refraction tabulate it according to temperature and pressure on the hypothesis of a constant lapse rate of 3°F per 1000 feet. The reason is, that while temperature and pressure can be readily measured at the time of observations, the determination of lapse rate imposes a hard task, which is generally not possible at a field station. It must be realised that this value often differs widely from the actual refraction on account of prevailing gradients being different from the assumed value. No universal law can be found which would be applicable to all cases. This is where the main uncertainty lies. Estimates of refraction have of necessity to be based upon average weather conditions ; the actual position on any day at the time of observation may depart considerably from them.

It so happens, however, that near midday, the amount of refraction is minimum and at this time the variations in the temperature gradient from day to day are least. The modern practice accordingly is to overcome irregular effects of refraction by confining the observations of vertical angles between the hours of 12 noon and 3 P.M.

The above technique of observing reciprocal vertical angles at the time of minimum refraction on different days has been found to yield satisfactory results in the case of triangulation stations which do not necessitate long and steep rays. The observations of vertical angles to peaks, however, can neither be reciprocal nor is it always possible to take such observations at the time of minimum refraction. Quite often, this happens to be the period during which the peaks are generally hidden by clouds. In deducing the heights of such inaccessible peaks by making use of some assumed value of the coefficient of refraction, large discrepancies are bound to occur.

To get an idea of the amount of refraction, it might be of interest to mention, that the difference between morning and midday refraction amounted to 500 ft in the height of Dhaulagiri (*26,785 ft*). The observations to Mount Everest necessitate a refraction correction of as much as 1375 ft, so that even if a 20 per cent error is made in its estimation, the resulting height would be in doubt by over 200 feet.

(*iv*) *Variations of snow* — Another source of doubt in the height of snow-peaks is the variation in the amount of snow during the course of the year. There is no means of evaluating it precisely.

3. Heights of snow-peaks

The chart on page 169 shows some of the well-known snow-peaks of the Himalayas. Of these only three—Mount Everest, K^2 and Kanchenjunga are above 28,000 ft in height. (In comparison, it might be illustrative to remark that the Rockies in America are less than 20,000 ft high). These mountains are the highest in the world and were observed by the surveyors from about half a dozen stations in the plains in the years (1848-50), (1857-59) and (1847-50) and their accepted heights are 29,002, 28,250 and 28,146 ft respectively.

Two other high peaks situated in Nepal Himalayas are Makalu (*27,790 ft*), observed in 1846-48 from six stations and Dhaulagiri (*26,785 ft*) observed in 1948-49 from seven stations. The famous Nanda Devi peak in Kumaun Himalayas (*25,645 ft*) was observed in 1841-42 from nine stations.

It should be clearly understood that for a variety of reasons, considerable uncertainty exists in the adopted values of the heights of these peaks, observations for which were taken about a century ago under several handicaps. To mention but a few—

(*i*) The peaks of Nepal Himalayas had to be observed from long distances (over 100 miles) in the plains, as entry into Nepal was forbidden. This introduces several sources of error of considerable amount.

(*ii*) The adopted heights of the stations of observation themselves in those early days were sometimes in considerable error.

(*iii*) Most of the observations could not be taken at the time of minimum refraction as the high peaks generally get hidden by mist and

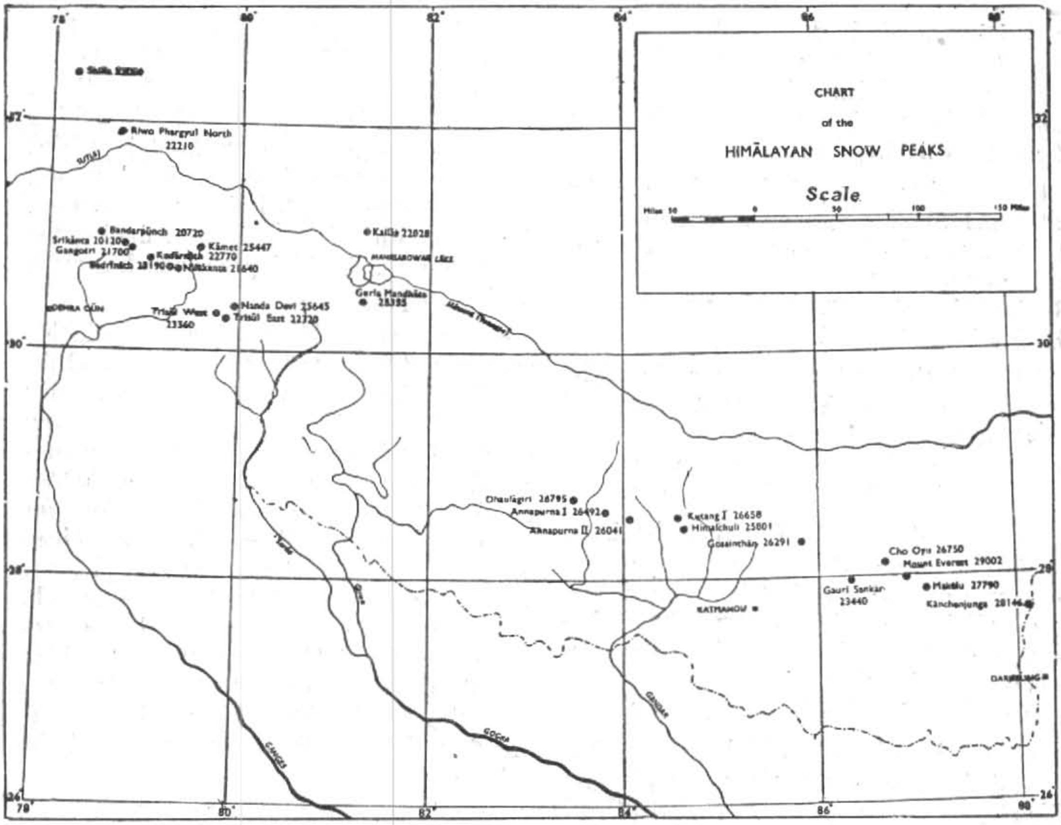

Fig. 1

clouds at this time. The peaks are most clearly visible at or before sunrise but this is precisely the danger period for observation of vertical angles.

(*iv*) The computations in certain cases were also faulty. Plumb-line deflections and distortion of the mean sea level were ignored. The coefficients of refraction were adopted by trial and error to obtain best possible concordance between the results from different stations, but even then there was wide scatter. Thus, the heights of Dhaulagiri derived from various stations ranged from 26,773 to 28,640 feet. The adopted value of 26,795 ft manifestly gives a misleading idea about its accuracy.

Similar is the case with the value 29,002 ft adopted for Mount Everest. Its exact significance is not understood by most surveyors not to speak of the laymen. The last digit 2 in this figure gives a far exaggerated notion of its accuracy and yet if it is omitted, it might lead people to believe that 29,000 ft was only a round number. A detailed discussion of its height is given by the author in Survey of India Technical Paper No. 4—" Mount Everest—Its Name and Height. " A short summary would not be out of place here.

This mountain was observed in 1849-50 from six stations in the plains of India about 100 miles away from it.

The heights of Mount Everest as computed from these stations were 28,991.6 ; 29,005.3 ; 29,001.8 ; 28,998.6 ; 29,026.1 and 28,990.4 ft respectively. The mean of these is 29,002 ft and this is the figure adopted upto the present time.

In later years, observations to Mount Everest were taken from the Darjeeling hills in the course of the normal survey programme.

Its height was derived from these observations by Sir Sydney Burrard in 1905 by assuming a coefficient of refraction of 0·05 and worked out to be 29, 141 ft but he never claimed any finality for it.

By a further manipulation of the older data, such as allowing for fall to midday for those observations which were taken in the early mornings, the Survey of India later on obtained the values 29,079 ft and 29,149 ft for the height of Mount Everest.

Although these later values may be slight improvements on the adopted value of 29,002 ft due to modifying the original faulty computations, they are by no means precise enough as judged by modern standards.

However, despite the fact that the figure 29,002 ft was computed in a most incomplete manner, *e.g.*, with a definitely wrong refraction coefficient, ignoring the plumb-line deflections and with no idea of the datum surface, it is possible that the various errors may have conspired in the direction of cancellation.

The heights of all other high peaks such as K^2 (*28,250 ft*), Kanchenjunga (*28,146 ft*), Dhaulagiri (*26,795 ft*), Nanga Parbat (*26,620 ft*), etc. also suffer from similar defects. The existing observational data is far too old and incomplete and so many doubtful factors enter into it that no matter how it is manipulated, it cannot produce a result final enough to justify supersession of the traditional values.

Further observations carried out on systematic lines are needed for the purpose. To get the sea level height, it is essential first to correct observed angles for deflections and get spheroidal heights, and then to carry out deflection observation along the hill sections to get an estimate of the deviation of the geoid from the spheroid below the peak and apply it to the spheroidal height to obtain the geoidal height. This would be very difficult as the carrying out of deflection observation in high mountains would entail on arduous programme.

A much more feasible way, of getting the most reliable value of peaks, is to organise a geodetic expedition to carry out short sided triangulations close to them.

Vertical angles, to the peaks, should be observed from high stations of this triangulation at distance of 20 or 30 miles from them. Refraction at these high altitudes is neither so large nor so erratic as in the low lying plains and so can be tackled better. Furthermore, it can be demonstrated that this method does away with the necessity of finding the geoidal form under high peaks which is quite a difficult proposition.

So far as Mount Everest is concerned, this work would be quite inexpensive, as a chain of minor triangulation has been run recently in Nepal to provide control for the mapping of Kosi Catchment area. It had been proposed to extend this triangulation slightly northwards, to provide suitable stations for vertical angles to Mount Everest. These stations were to be of reasonable height, not presenting any great difficulties of approach. A programme of observations had been prepared for the field season 1951-52, which would have put an end to the controversy regarding the height of Mount Everest but the financial stringency has frustrated the scheme.

4. Search for Peaks higher than Mount Everest

The publishing of different values 29,002 ; 29,080 ; 29,141 and 29,149 ft for the height of Mount Everest has produced several erroneous notions in various quarters. All these values have come to be regarded as having been established independently by the Department. Some geologists have asked, whether they can be taken as an indication that the Himalayas are rising. The cartographers are no less puzzled and an impression has got round that the lowest of the different values had been accepted for ground mapping purposes and that the situation needed review with the introduction of ' air maps ' as opposed to ground maps. The U.S.A. authorities in their air maps have printed the highest known value 29,149 ft for Mount Everest to provide an adequate margin for safe navigation on the plea that it is one of the recognised values by the Department. This is fallacious reasoning and the difficulty is more apparent than real. 29,002 ft was not adopted on account of a convention to use lowest values of all determinations;

rather it was the first attempt at deriving height of Mount Everest in 1852 when knowledge regarding refraction, deflections and geoid was meagre. With a more rational treatment of refraction, and other factors various other values have been derived some of which are above datums which are not recognised by the barometer in an aeroplane. Aircraft surely should provide a much higher margin of safety than discrepancies likely to be met with in various values for the height of a peak.

Not long ago, there were sensational press accounts of the plans of Milton Reynolds, a millionaire aviation enthusiast in a new venture in search for a peak higher than Mount Everest. The expedition was to map the so far unclimbed and unmeasured peaks of the Amne Machin mountains in northwest China. This range is supposed to be almost inaccessible and contains several of the highest peaks in the world. The War time " hump pilots " had reported colossal heights for these unmarked mountains and the allies lost quite a number of airmen in this area.

It might be mentioned here, that search for a peak higher than Mount Everest by air flights has several limitations.

The graduation of aircraft altimeter is based on a standard formula derived by adopting a so-called International Standard Atmosphere. This assumes inter alia that the air is dry and has the same chemical composition at all latitudes. The lapse rate for heights between 0 and 11,000 metres is assumed to be —3·566°F per 1000 ft, the temperature at sea level as 15°C, and the value of gravity is taken to be constant and equal to 980·62 C.G.S. Considerable corrections to the altimeter readings would be necessary to allow for local departures from the idealised conditions of the basic formula on which the graduations rest and these will usually not be obtainable. In any case, aeroplane altimeter especially at such altitudes are apt to give erratic readings.

Before the height of a new peak of the same order of magnitude as Mount Everest can be discovered with certainty it will have to be observed and computed by rigorous methods making due allowance for observational errors as well as others brought about by the various meteorological factors and this is by no means easy. The best chance would be by ground observations from close by peaks taken at proper times with proper care.

5. The Himalayan Uplift

It is a common geological belief that the Himalayas are still rising. In fact, a great mass of geological data has been advanced to testify to this. To get quantitative estimates of this rise, periodic geodetic observations of vertical angles are needed. For such high peaks as Everest, K², Kanchenjunga and Nanga Parbat, no repeat observations ave been taken although the fresh assessments of their heights have been misconstrued as indicative of Himalayan uplift. As has been explained in the foregoing paras, the uncertainty of their absolute height determination is so great that it is fatuous to use them for any quantitative estimates of the extremely slow rise which the geologists postulate. Such peaks do not form a useful subject for this study. Secular variations in the elevations of peaks are best determined by carrying out repeat vertical angle observations to them from one station under similar conditions. Five peaks—Bandarpunch, Srikanta, Jaonli, Kedar Nath and Nag Tibba were observed in 1907-08 and repeat observations were taken to them in the years 1932-33. The indications were, that no measurable changes had occurred in the heights of these peaks.

6. Conclusion

The mighty Himalayan range is full of magnificent array of snow-peaks before some of which even the highest mountains of other countries pale into insignificance. Many of these, such as Badrinath and Gangotri are stations of pilgrimage. Mount Everest inspires such awe and reverence amongst the Tibetans, that they have given it the expressive name of Chomo Lungma, meaning " The Goddess mother of the World." The scaling of the heights of all the greater peaks of the Himalayas is a problem yet to be tackled. The figures accepted for their heights give a misleading idea of their precision, *e.g.*, 29,002 ft for Everest is not correct to the nearest foot as it appears to connote. The various factors which introduce uncertainties are too difficult to be understood by a layman who wants to know the facts of the situation. Heights of important peaks were observed long ago when entry into such countries as Nepal was forbidden and when knowledge about mean sea level and refraction was meagre. All these traditional values are in doubt.

Many more observations are needed before heights of such peaks as Everest and K^2 can be known with sufficient accuracy and a new mode of attack has to be inaugurated instead of the earlier methods. Among other things, detailed comprehensive theoretical and practical investigations on refraction are needed urgently. Sub-refraction and super-refraction can produce considerable variations in resulting heights.

There is a great need for geodetic expeditions in Himalayan regions. For want of deflection data, the form of the geoid under the peaks cannot be estimated with any degree of precision. If the Himalayas were just extra loads on the earth, the rise of the sea level under Mount Everest would be 1100 ft or so. If they were perfectly compensated by deficient mass underneath them, the rise would be about 80 feet. Both these are extreme hypotheses. There is indisputable evidence from indirect sources that the Himalayas are partially compensated and that they are not mere excrescences on a globe which without them would be in hydrostatic equilibrium. Not only is our knowledge, of the actual compensation of the Himalayas, deficient on account of lack of observational data but also in India there are further complications, introduced by the fact, that there are very important subcrustal features in Central India which modify greatly the effect of the Himalayas. Whatever meagre evidence there exists, about the compensation of the Himalayas, is due to gravity data. The gravity anomalies, at most of the Himalayan stations, tend to be positive indicating they are under-compensated. But the exact amount of under-compensation is not known and so a theoretical estimate of the rise of the geoid above spheroid, under the high peaks is not possible.

Very interesting geodetic and geophysical results were obtained by the German Himalayan expedition of 1934 to Nanga Parbat. Triangulation was carried out and heights were observed to provide rigid framework for a contoured map of the whole of Nanga Parbat group. In addition, meridional plumb-line deflection observations were made at 15 stations and the results are discussed in "Zeitschrift Fur Geophysik," Vol. XIII, 1937, in an article by K. Jung, "Plumb-line Deflections round Nanga Parbat and their Geophysical Interpretation". Nanga Parbat is about 2000 metres higher than its surroundings, so one would expect plumb-line to be deflected towards it. But it was found to be pointing directly away from it, indicating a zone of large mass defect, *i.e.*, over compensation under it. There is a lot of scope for geophysical work in the Assam Himalayas.

Considerable funds are necessary for the geodetic problems associated with high peaks and it will never be possible for the Survey of India to cope with them from its limited budget. There is only a difference of 104 ft between the heights of K^2 and Kanchenjunga and this figure is within the errors of the older observations. New work may put Kanchenjunga above K^2. This upset may only be of sentimental interest but it is still worth pursuing. Owing to their pre-eminent heights, we want as precise a value as possible for the heights of our peaks. Apart from anything else, they would give an estimate of the maximum load that the earth's crust can support.

In spite of financial stringency, it would appear desirable and even necessary to make an intensified effort to increase our knowledge of the Himalayas and not depend on foreign expeditions for this purpose.