

# THE ARUN RIVER DRAINAGE PATTERN AND THE RISE OF THE HIMALAYA

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THE Arun river collects its waters from the north side of the Himalaya and from the south side of the lower indefinite range known as the Nepal-Tibet watershed. After flowing approximately eastward along the grain of the country it turns abruptly south and in a series of magnificent gorges cuts through the Himalaya between Mount Everest and Kangchenjunga. The remarkable behaviour of the Arun and several other rivers in cutting across from the plateau of Tibet through the much higher Himalayan range has frequently been commented upon, and two alternative theories, with very different implications for the student of the geology and geography of the Himalaya, have been put forward to explain it. One of the theories postulates that at an early stage the Himalaya had ordinary consequent drainage, the rivers flowing north and south from the crest. This simple drainage pattern is considered to have been modified to its present form by some of the south-flowing rivers cutting back through the range and capturing rivers on the Tibetan side. The much greater precipitation on the south side of the range and the much steeper fall and therefore greater erosive power are put forward as possible reasons for the unusual behaviour of the south-flowing rivers. The alternative theory postulates that the Arun and similar rivers always had their present courses which, when they were inaugurated, were the easiest routes down an irregular surface sloping towards the Gangetic plain. Subsequently the Himalayan range is considered to have risen up across the rivers, but so slowly that by vigorous erosion they were able to keep open their original channels. If this latter theory of antecedent drainage, as it is called, could be substantiated, it would provide definite evidence of an important early stage in the surface form of the Himalaya, and it would also give a definite indication of the mechanism by which the Himalaya has grown to its present height.

The theory that the Arun has cut back through the Himalaya and captured Tibetan rivers has been supported by Hayden<sup>1</sup> and Heron.<sup>2</sup> Fox,<sup>3</sup> in a discussion of Heron's paper, and Odell<sup>4</sup> have tentatively suggested the alternative view. Many others, especially Medlicott, Oldham, and Burrard,<sup>5</sup> have discussed similar cases or the general case of which the Arun is an

<sup>1</sup> Hayden, H. H., "The geology of the provinces of Tsang and U in Central Tibet," *Mem. Geol. Surv. India*, vol. XXXVI, Part 2, 1907, p. 5.

<sup>2</sup> Heron, A. M., "Geological results of the Mount Everest Reconnaissance Expedition." *Mem. Geol. Surv. India*, vol. LIV, Part 2, 1922, pp. 215-34, and *Geogr. J.* 59 (1922) 418-31.

<sup>3</sup> Fox, in the discussion of Heron's paper, *Geogr. J.* 59 (1922) 431-6.

<sup>4</sup> Odell, N. E., "Observations of the rocks and glaciers of Mount Everest," *Geogr. J.* 66 (1925) 300. And Appendix in 'The fight for Everest,' pp. 305-6, 1925.

<sup>5</sup> Summaries with references are given in Burrard, S. G., and Hayden, H. H., 'A sketch of the geography and geology of the Himalaya Mountains and Tibet,' revised by S. G. Burrard and A. M. Heron, Delhi, 1934, pp. 261-6 and 347-9.

example, but the evidence has not been sufficient to come to a final conclusion. During the 1933 Mount Everest expedition there was an opportunity of seeing much of the Upper Arun, and I propose to give here some general observations on the physiography of the region and then to describe certain features which I believe afford definite evidence that the Himalayan range has risen across the course of the Arun without modifying to any significant extent the original direction of the river.

*The Upper Arun and its tributaries*

The relief of the mountain country through which the Arun flows can be most satisfactorily shown on a small-scale map by giving spot heights along the course of the river and indicating the position of the high land by marking all peaks of certain height intervals. Thus on the folding map all peaks between 19,000 and 22,000 feet are shown by small triangles, and all peaks above 22,000 feet by larger triangles. By choosing these particular heights the position of the indefinite range, the so-called Nepal-Tibet watershed<sup>1</sup> which forms the northern limit of the Arun drainage system is well brought out, while the main Himalaya is shown as a range with many peaks higher than this. From the Survey of India maps on the scale of 4 inches to 1 mile<sup>2</sup> the profile of the river can be drawn (see folding map). The actual profile is very different from that of a graded river, the form given in a misleading diagrammatic section by Burrard.<sup>3</sup> An abrupt increase in gradient occurs where the river leaves the plateau and begins to cut through the Himalaya, and it is here, soon after the point where the valley floor becomes convex, that the Yo Ri gorge, the first of the striking gorges through which the Arun flows, is found. The main gorge begins at Kharta Shika and with occasional broadenings continues for the next 50 miles. Twenty miles beyond this point the Arun joins the Kosi, then shortly reaches the southern boundary of the Himalaya; here the river is at a height of only 200 feet although still 400 miles from the sea.

In Tibet the Arun has at least two names, the Men Chu for the first 60 miles and then the Phung Chu as far as the Nepal-Tibet boundary. In this paper I propose to simplify the nomenclature and use the name Arun for the whole of the river. The Arun rises on the north slopes of Gosainthan, a peak of the Himalaya 26,291 feet high, and for the first 150 miles its course is mainly east along the strike of the rocks. Heron, who visited the uppermost part of the river as a member of the first Mount Everest expedition, describes how the few abrupt bends that the river makes are such that it avoids areas where granite veins have hardened the rocks. From his geological mapping Heron also showed that in Tibet the Arun tends to flow along synclinal zones. In a region of mature topography rivers usually follow the course of anticlines, since the rocks are there more easily eroded. The fact that the Arun

<sup>1</sup> Formerly regarded as an easterly extension of the Ladak range but now given this name by Burrard.

<sup>2</sup> According to a personal communication from Professor Kenneth Mason the probable error of these maps is not large enough to affect significantly the profiles given in this paper.

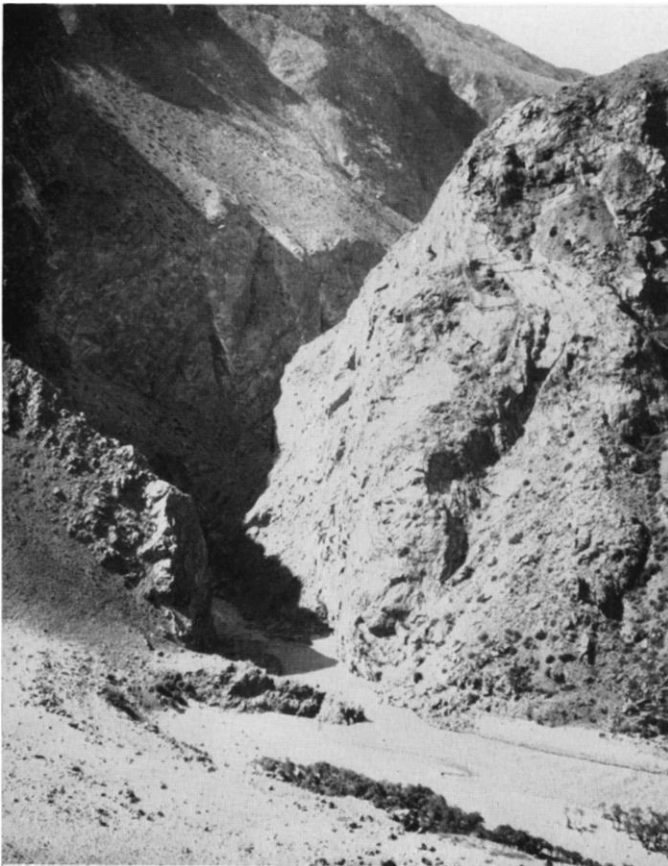
<sup>3</sup> *Op. cit.*, Chart XXXVII.



1. The Upper Arun  
near Pangla, south  
of Shekar



*2. Yo Ri gorge and Kuyok La. Moraine mounds in the middle distance half buried by post-glacial gravels*



*3. Entrance to Yo Ri gorge*

still flows along what were tectonic valleys in the original surface shows how relatively recent is the development of the drainage system.<sup>1</sup>

At present, in its upper part, the Arun is a braded river flowing over an extensive spread of gravels. Harder masses of rock stand up as subsidiary hills within the valley (Plate 1), and where hard bands cross the river minor gorges occur.<sup>2</sup> The valley is still youthful in character, but there has been a recent prolonged period of aggradation which has filled the bottom of the valley with a level spread of gravel. Still more recently the river has begun to cut into the gravels, forming a system of river terraces—features which have struck the eye of all travellers to the region. Although there are many indications of a complex system of terraces which will require more detailed maps and careful levelling for their interpretation, yet the last great spread of gravels and the terraces developed from them can be widely identified even during a hurried journey through the country. Moreover, the age of this conspicuous period of aggradation can be fixed relatively to the period of maximum Quaternary glaciation. Thus a quarter of a mile above the confluence of the Dzakar Chu and the Arun the terminal moraine mounds of a glacier coming down from the Nyonno Ri range are surrounded and almost buried by the gravels of the recent period of aggradation (Plate 2). This moraine is the lowest observed in the district and was formed during the maximum extension of the Quaternary glaciers. Further evidence of age is also found at Rongbuk, where the same spread of gravels merges into the outwash fan of the lowest moraine of the Rongbuk glacier. No fourfold division of the Quaternary glaciation such as is suggested for other parts of the Himalaya by the work of Dainelli, H. de Terra, and T. T. Paterson has yet been recognized in the Arun region. All that can be stated at present is that the spread of gravels was formed at the time of, and after, the maximum Quaternary glaciation of the region. For convenience of reference these gravels will be called the post-glacial gravels and the terraces developed from them the main terraces.

About the middle of its course in Tibet, near Shekar Dzong, the Arun has cut only shallowly (50 feet or less) into the post-glacial gravels. Traced down stream the river is found to have cut increasingly deeper. The Dzakar Chu, a tributary to the south, shows the same features. The heights of the terraces have only been estimated by eye and no reliance must be placed on the absolute values given, but the general increase down stream is obvious. Traced from Tashi Dzom up stream, the terraces of the Dzakar Chu decrease in height above the river, but shortly after Chodzong they begin to increase again, and near Rongbuk they are well over 100 feet. This rather remarkable behaviour of the terraces should be searched for in other streams which turn south towards the crest of the Himalaya. If it is found to be widespread it may be that it is an effect of the recent gradual upwarping of the main Himalayan zone for which evidence is given below.

The largest tributary of the Arun is the Yaru Chu, which rises in the hills

<sup>1</sup> Pascoe, E. H., in the discussion of Heron's paper, *op. cit.*, p. 436, has suggested an alternative reason for this relation between the river courses and the synclines, but it seems probable that Heron's original suggestion is the right one.

<sup>2</sup> Heron, *op. cit.*, p. 420.

north of Kampa Dzong and enters the Arun from the east after passing through the northern continuation of the Nyonno Ri range in the Rongme gorge. Much of the middle part of the Yaru valley has been recently occupied by a shallow lake of which the small lake near Tengkye and the marshes to the south and south-west are the remnants. Spender<sup>1</sup> has stated that he found evidence of this lake east of the village of Sar. Half a mile north of Linga, which lies some 6 miles east of Tengkye Dzong, there is a curious long spur of gravel pushing out southward from the hills on to the flat plain. In 1933 I examined this feature and found that it was a delta of coarse materials put down by a stream when the plain about Linga was covered by a lake some 300 feet deep. The extent of the lake is not known, but should be easily determined when the region is carefully mapped.

The Chiblung Chu, a tributary of the Yaru Chu, cuts through the northern continuation of the Nyonno Ri range at Jikyop in a gorge like that on the Yaru Chu at Rongme. The height of the main terrace in the gorge is some 400 or 500 feet above the river, but traced up stream the height rapidly becomes less, and 7 miles above the gorge is only about 30 feet. Exactly similar changes in the relative height of the main terrace and present river-level are to be seen in the Rongme gorge and have been commented upon by Spender.<sup>2</sup> It would be of great interest to determine with reasonable accuracy the absolute height of the post-glacial gravels as the continuation of the Nyonno Ri range is approached. Without this information the reason for the behaviour of the terraces is in doubt; it may be that the gravels have not been upheaved since deposition, the change in height of the terraces above the river being the effect of rejuvenation which has only worked a small distance to the east of the range. An alternative however, which I believe from the general tectonics of the region to be more probable, is that uplift of the range has caused local upwarping of the recent gravels. Near Sar, also to the east of the Nyonno Ri range, I found fine-grained river or lake deposits tilted away from the range at 20°. A brief examination showed no evidence which would suggest that the high dip was due to land slips, solution effects, or thrusting by glaciers, and the silts seemed too fine-grained to be the fore-set beds of a delta originally deposited at this angle. I had to conclude that the dip was the direct effect of localized earth movement perhaps near a fault. It seems likely that the former lake occupying part of the Yaru Chu valley and the apparently upwarped terraces in the Rongme and Jikyop gorges are the result of recent uplift of the Nyonno Ri range.

#### *The extent of the maximum glaciation in the Upper Arun valley*

Before describing the remarkable gorges which occur on the Arun river I wish to review briefly the evidence which seems to me to eliminate the possibility that ice, either as a sheet or as glaciers, has played any important part in their development. All travellers agree that in Tibet evidence of an ice-sheet or of extensive valley glaciers is nowhere conspicuous. A prejudice in favour of the view that Tibet was once covered by ice seems to result from the undoubtedly far greater extent of the Himalayan glaciers in past time.

<sup>1</sup> Spender, M. A., *Geogr. J.* 88 (1936) 293.

<sup>2</sup> Spender, M. A., *op. cit.*

For instance, the Zemu glacier coming from Kangchenjunga formerly extended down to a height of 9000 feet.<sup>1</sup> Had the glaciers running northwards from the Himalayan peaks had a tendency to persist to similar low levels, it is clear that the whole of southern Tibet would have been covered by an ice-sheet; this is the view originally taken by Blandford and later by Trinkler.<sup>2</sup> Odell<sup>3</sup> has tentatively suggested that the Upper Arun drainage area shows some general evidence of a former ice-sheet, but with this I am not able to agree. Hayden stated that moraine from the mountains to the south occurs on the hills near Kampa Dzong. This however might be explained by a single glacier tongue from the Pauhunri group, though I observed neither near Kampa Dzong nor in the Kanchenjhou and Pauhunri region anything which would suggest this. An extension of the glaciers to far lower levels in the Himalaya than in Tibet is to be expected because of the steeper gradients, and because of the far higher precipitation. Even during a secular lowering of temperature such as would have no doubt occurred during the Glacial Period it is probable that Tibet would require a considerable increase in precipitation to nourish an ice-cap. In Pleistocene times the monsoon may have been a little stronger and the Himalaya a little lower, yet I believe that the precipitation reaching Tibet was still too small to allow an ice-cap to form.

Within the Arun drainage area I observed no definite traces of the effects of ice away from the higher summit of the Nepal-Tibet watershed and away from the Himalaya; there were on moraines, no "roche moutonnée" or striated surfaces, no "crag and tail" effects, no U-shaped valleys or glacially truncated spurs. It has been suggested that Tibet would support an ice-sheet which would be so nearly stagnant that the usual effects of moving ice would not be produced. Such a view is difficult to disprove. However gradients in much of England where the effects of the Quaternary glaciation are conspicuous are much less than in this part of Tibet, and small hills, as for instance those which rise up in the valley of the Phung Chu near Pang La (Plate 1), should not have remained unmodified by the ice had it ever covered the region. The waning stages of an ice-sheet as it broke into lobes occupying the lower valleys should in particular be indicated now by terminals and lateral moraines, but none have yet been found. The present glaciers flowing north from the Himalaya all show evidence of being more extensive in the past, but the amount of extension was small. The lowest moraine of the Rongbuk glacier is at Rongbuk, only 5 miles from its present snout. The extension of other glaciers in the Nyonno Ri range, the Lashar Plain valley, the Lhonak valley and about Pauhunri is comparable with the extension of the Rongbuk glacier. Thus in this part of Tibet there only seems to be definite evidence of a slightly greater Quaternary extension of the present glaciers and no evidence for the former existence of an ice-sheet.<sup>4</sup>

<sup>1</sup> Garwood, E. J., Appendix, pp. 298-9, to 'Round Kangchenjunga,' D. W. Freshfield, London, 1903.

<sup>2</sup> *Geogr. J.* 75 (1930) 225-32.

<sup>3</sup> *Geogr. J.* 66 (1925) 311-13.

<sup>4</sup> De Terra, from his travels in Little Tibet, has come to a similar conclusion. *Geographical Review*, vol. XXIV, 1934, p. 32.

*The Yo Ri gorge*

Yo Ri, a mountain 17,987 feet high, dominates on one side the remarkable uppermost gorge of the Arun, while on the other it overlooks a low pass, the Kuyok La, crossed by the mule track up the Arun valley as no way is possible through the gorge. The present configuration of the region is remarkable because the river has cut a deep, artificial-looking gorge like a railway cutting between high mountains, whereas the way by what is now the Kuyok La would seem to have offered a much easier route. Twelve miles above the gorge, where the Arun is joined by the Yaru Chu, the river is flowing in a broad valley over the post-glacial spread of gravels. Traced down stream the valley remains open, but the river cuts gradually deeper into the gravels lying in the bottom of the valley until at Kharkung, immediately before the gorge, the river is flowing 700 or 1000 feet below the upper surface of the gravels. Here the river plunges into the mountain side (Plate 3). The pass which the river avoids is only about 1800 feet above the river, and is broad, with slopes of easy gradient. The steep walls of the gorge tower 6000 feet above the river on the west side and still more on the east. The gorge runs south for 4 miles then turns through a right angle and continues in that direction for another 4 miles before ending as suddenly as it began in a broad valley. This valley is also floored by post-glacial gravels belonging to a set extending up the Dzakar Chu, a tributary of the Arun. Into these gravels the rivers have cut 100 feet or so (Plate 2).

The Yo Ri gorge was briefly described by Heron in a paper to the Society,<sup>1</sup> and it was singled out for discussion after the paper by Mr. C. S. Fox and Mr. A. R. Hinks, who both realized its extraordinary interest. No satisfactory explanation of it however was reached. When actually confronted with the gorge it is impossible not to feel that, if this apparently unreasonable behaviour of the river could be understood, it would throw light on the cause of the anomalies of the whole Arun drainage.

Heron observed that the Yo Ri gorge is cut in hard gneiss while the pass to the east is cut out of comparatively soft schists. I believe that the germ of the explanation of the gorge lies in this observation which was confirmed in 1933. The change from the relatively soft schists of the Kuyok La to the hard resistant gneisses is abrupt. Some shattering of the harder gneiss, probably produced by faulting, was noticed at the entrance to the gorge. This has not the appearance of the usual Tertiary gneisses, but seems rather to belong to what I have tentatively called Peninsular India type.<sup>2</sup> Whether faulting or an unconformity has produced the abrupt change in the rocks was not decided.

Had the Arun ever flowed over the Kuyok La in relatively soft rock it would never have changed by any ordinary process of river capture to its present course through the corner of a mountain mass of much greater height and composed of harder rock. On a small scale ice-sheets have produced channels across spurs, but not only is the Yo Ri gorge on a very different scale but there is no evidence in the region of a former ice-sheet. The enormous thickness of sediments eroded from the region must be taken into considera-

<sup>1</sup> *Geogr. J.* 59 (1922) 421, and plates opposite pp. 420 and 421.

<sup>2</sup> 'Everest 1933,' p. 320.

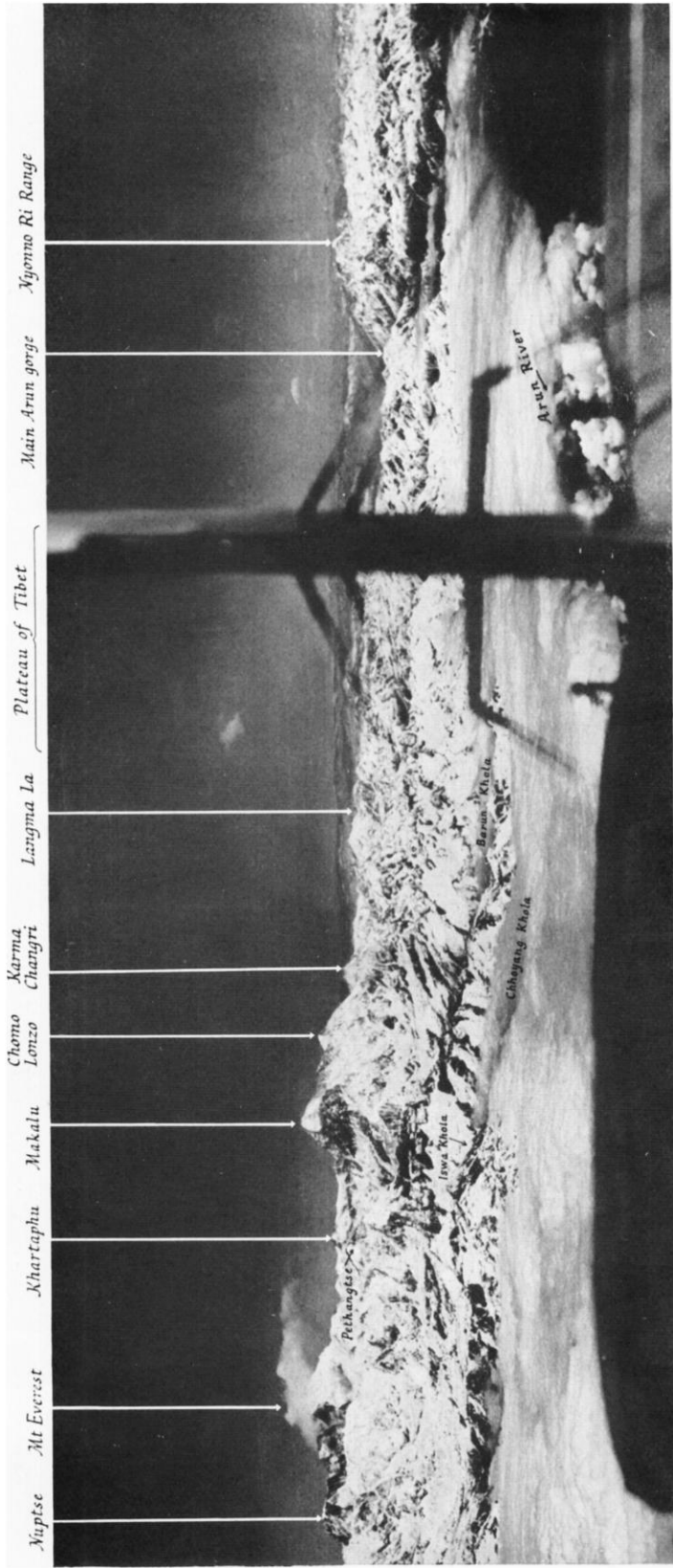




4. River Arun immediately above the main gorge



5. Looking down the main gorge of the Arun



6. Looking north at part of the Great Himalaya Range

Houston-Mount Everest Flight.  
By permission of "The Times".

tion in any explanation of the present gorge. Above the present surface there formerly existed the Mount Everest Limestone Series, the Lachi Series, and the Jurassic and Cretaceous beds, in all many thousands of feet. The Arun once flowed on a surface high above the present one, and the course it now follows may be taken as giving an indication of the form of this surface since the river must have followed the easiest downhill route. In this surface the river incised itself and formed a valley; at the same time general erosion by rain and streams lowered the whole area. The Arun, in its upper part, is still cutting into soft sedimentary beds, and as a result the valley is wide with gently sloping sides. Where the Yo Ri gorge occurs, the river, in cutting down, has come across hard gneisses. The gorge which has been produced, as in many other cases, is simply the result of the change to harder rocks. Rain, streams, and the other erosive agents which tend to widen valleys have had far less effect on the hard gneisses of Yo Ri than on the softer sediments farther up stream, and thus the valley sides remain steep. The change from the two types of rock occurs abruptly. The Kuyok La marks the beginning of the softer rocks and has been produced by the general erosion of rain and small streams and not by the river.

It is possible to decide what causes the change in the hardness of the rocks to which the formation of the gorge is due. The rocks forming the central core of the Nyonno Ri range were reached at Yo Ri and on the east side of the range above Phuru. They proved to be gneisses of Peninsular India type which underlie the schists and gneisses of the Mount Everest Pelitic Series and Limestone Series. The Nyonno Ri range is therefore structurally an anticline which brings up deep-seated and harder rocks. The deflections in the courses of the Arun and the Yaru Chu round the Nyonno Ri range suggest that an early stage of this anticline existed as an upward bulge of the surface on which the drainage was established. The increase in height of the main terraces above the river as the Yo Ri gorge is approached suggests <sup>1</sup> that uplift is still going on (*cf.* below). As uplift and denudation continue it is likely that the Yaru Chu where it makes an abrupt elbow bend at Sar will one day find itself cutting into the harder gneisses below the sediments on which it is now flowing and then another gorge very like that at Yo Ri will be formed.

The most interesting feature of the Yo Ri gorge is its close association with the low pass of the Kuyok La. If the original surface on which the Arun flowed had been anything like the present one then the river would have taken a course over the lower ground to the west of Yo Ri which is now the Kuyok La. Since this is not the case the Arun must have firmly established its course before the development of the present form of the land. Some of the present greater relative height of the Nyonno Ri range above that of the land to the north-west and east is to be ascribed to the direct effect of the anticlinal uplift, but much is probably the result of a secondary effect, namely, the resistance to erosion of the hard gneisses of Peninsular India type which form the range. Subjected to roughly the same intensity of erosion the hard

<sup>1</sup> This can only be suggested. The possibility that it is due to rejuvenation cannot be ruled out until accurate measurements of the absolute height of the terraces have been made.

rocks of the Nyonno Ri range are lowered much less than the softer rocks to the north-west, and thus is produced gradually a greater difference in height than is produced by the direct effect of uplift. The history of the development of the Yo Ri gorge, as I read it, implies that the Arun has had exactly its present course for a very long time, long enough in fact for the great inequalities in height between the Nyonno Ri range and the ground to the west to be developed.

*Minor gorges on the Yaru Chu and Chiblung Chu*

The Yaru Chu crosses the continuation of the Nyonno Ri range by the Rongme gorge already mentioned, and its tributary, the Chiblung Chu, crosses the same range a few miles to the north by the similar Jikyop gorge. To the east of the range there is a low col between the two river valleys which is 2000 feet lower than the range itself. Heron<sup>1</sup> commented upon this and suggested that the Yaru Chu once flowed over the low col and joined the Chiblung Chu. He supposes that a stream has since cut back along the present river gorge at Rongme and captured the Yaru Chu. An explanation essentially the same as given for the Yo Ri gorge seems however more satisfactory. The rocks at the col are almost unmetamorphosed and easily eroded sediments, while those of the range have been hardened by metamorphism which was sufficiently intense for biotite to have developed in the slates. General denudation must have been more effective over the region to the east of the range and lower ground is therefore to be expected there. Further, the height of the river terraces and the existence of the former Yaru lake suggest that there has been localized uplift of the Nyonno Ri range. This would also have the effect of producing relatively low ground on the east side. Besides the direct effect, the greater uplift has exposed more deep-seated rocks which, being harder, are less easily eroded. The difference in the hardness of the rocks is the factor essentially responsible for the gorge form, but it is itself the result of a localized region of special uplift.

*The main Arun gorge and its origin*

For 11 miles below the Yo Ri gorge the Arun river flows in a moderately wide valley floored by the post-glacial gravels. The river is at present cutting into the gravels and the terraces lie 100–200 feet above the river. The main Arun gorge begins abruptly just below the confluence of the Kharta Chu. From a spur 1000 feet above the river at the entrance to the gorge a traveller may look north over a treeless Tibetan landscape with the river flowing between high gravel terraces (Plate 4). Looking south from the same point the view is typically Himalayan (Plate 5); the valley is a narrow wooded defile with such steep sides that it cannot be followed by a mule track. The first description of this gorge was given by members of the Mount Everest reconnaissance expedition<sup>2</sup> and it was explored by Morris and Noel, members of the second Mount Everest expedition.<sup>3</sup>

From the junction with the Kharta Chu to Kimathangka the river descends

<sup>1</sup> *Op. cit.*, p. 421.

<sup>2</sup> 'Mount Everest; the Reconnaissance 1921,' pp. 110–11 and pp. 125–6.

<sup>3</sup> 'Assault on Mount Everest 1922,' pp. 89–102.

3300 feet in 18 miles, and the descent is made without definite waterfalls. The village of Lungto near Kimathangka is stated to be situated on a terrace or bench 1200 feet above the river,<sup>1</sup> and indeed traces of similar high terraces are to be seen at the top end of the gorge. Below this point the river enters Nepalese territory and Europeans have not been allowed to visit it, but from the maps it is clear that the river continues to flow in a gorge for another 40 miles, by which time it has descended to a height of only 2000 feet. This part of the valley can be roughly followed by a track while villages and cultivated areas occur at intervals.

The main gorge of the Arun is a magnificent example of a feature which occurs on many of the Himalayan rivers. The neighbouring Tista valley, being in Sikkim, is better known. The part of this river which is Tibetan in character is short, then the valley narrows and becomes a gorge of the same type as that of the Arun but not so impassable. This is no doubt because the river is smaller and is not able to cut downwards so fast as the Arun. The profile of the Tista (see folding map) is closely comparable with that of the Arun, and again the gorge corresponds to the lower half of the convex portion of the profile. Between Singhik and Dikchu the valley widens and some lateral erosion by the river begins. In this region the profile changes from being convex to concave again.

The profile of Himalayan streams and rivers will provide an interesting study when accurate data can be obtained. Even from the existing maps of Sikkim profiles can be drawn which show certain significant features. Thus streams of the foothills give an approximation to the even curve of a graded river. Streams which rise among the once glaciated hills from 12,000–15,000 feet high have this even curve interrupted. In the case of two valleys near the Natu La, which were visited during the 1933 Mount Everest expedition, the change from the normal curve of water erosion takes place at the lowest point of the former glaciers of the district. Here, where the ice had practically no forward motion and where masses of moraine were being put down, the valley lies above the level which would be expected if the curve of water erosion was continued to the watershed. At this point there is also a change from the narrow V-shaped valley, due to river erosion, to a broad upland valley with U-shaped cross-section. The nature and extent of glacial erosion are variously assessed by different observers and this is not the place to consider the problem, but I am convinced that useful conclusions would come from a careful study of the region about the Natu La.

The unusual profiles of the Arun and Tista, their gorges, and their peculiarity in cutting through a high range, seem to be related facts having the same cause. The views of different observers on the origin of the gorges are summarized by Hayden and Burrard in 'A sketch of the geography and geology of the Himalaya Mountains and Tibet,' which was revised in 1934 by Burrard and Heron. Despite difference in detail the various theories are essentially of only two kinds, those based on the idea of antecedent drainage and those based on the idea of river capture. In the revised monograph the Arun and Tista are still, without question, given as examples of rivers which have cut back their headwaters and captured Tibetan streams. The number

<sup>1</sup> 'Mount Everest; the Reconnaissance,' p. 125.

of factors controlling the behaviour of rivers in such a region as the Himalaya makes it impossible to reach a decision between the alternative theories by any deductive reasoning. It happens however that in the case of the Arun the existence of the remarkable Yo Ri gorge provides definite evidence in favour of antecedent drainage. The peculiarities of the topography about Yo Ri can only be explained on the view that the present course of the Arun was established a long time ago on a surface high above the present one, and that since that time some localized uplift and much general erosion has greatly modified the original form of the surface. The possibility of any recent capture of the upper part of the present Arun drainage by a Himalayan river seems therefore to be eliminated. The hypothesis of antecedent drainage also provides a reasonable explanation of the wide departure in the profile of the Arun from that of a graded river. The present profile of the Arun must be regarded as a temporary stage due to uplift of the Himalayan part of the valley along with the general uplift of the whole Himalayan region. The thick gravels flooring the valley were the result of a period of aggradation which extended into post-glacial time. It seems likely that this aggradation is to be ascribed to more vigorous uplift which partly dammed back the river or at any rate reduced its gradient. The original Arun must have found a downhill course among the minor undulations of the original mountain slope which formed the descent from the Tibetan plateau to the Gangetic plain, in those days perhaps an arm of the sea. No such general surface exists nowadays because since that time the range of the Himalaya has risen across the middle part of the river's course.

*Isostasy and the upwarping of the Himalayan region*

The effect of loading and unloading the crust of the Earth can be studied in the records of the formation and dissipation of the Quaternary ice-sheets of the world. Despite complicating factors, due for instance to changes in the volume of water in the oceans or to mountain building movements in the crust, observations in Scandinavia and North America demonstrate conclusively that when thick masses of ice have developed the crust has been depressed, and that later when the ice has disappeared the crust has slowly and somewhat irregularly risen. The difficulty of understanding the mechanism of these effects, the obscurity of their relations to the complex results obtained by gravity surveys, and the confusion that exists about the exact meaning of the word isostasy, should not be allowed to mask the fact that the loading and unloading of the Earth's crust has the effect of raising and lowering the average altitude of the surface by an amount which is roughly proportional to the load added or subtracted.

Where the Arun crosses the Himalaya the major topographic units are less complex than elsewhere in the range (Plate 6); the Tibetan plateau is a fairly even surface at an average height of about 16,000 feet, and the Himalaya closely approaches a linear feature. As a result of this simplicity certain probable effects of erosion can be better discussed for this region than for other parts of the Himalaya. The removal by the rivers of vast quantities of rock to form the deep valleys which here cross the range should have produced local uplift due to reduction of the load on the crust just as uplift has taken place

with the disappearance of an ice-sheet. Nansen<sup>1</sup> and Jeffreys<sup>2</sup> have both discussed from a theoretical point of view the nature and extent of the vertical uplift to be expected where valleys are formed and deepened in a mountain range. The Arun river provides evidence that the effects which Nansen and Jeffreys considered theoretically likely have in this part of the Himalaya actually taken place.<sup>3</sup>

Many observers have given evidence of recent and even present uplift of the Himalaya. Pliocene overthrusting in the foothills was proved by C. S. Middlemiss,<sup>4</sup> who also showed that the recent Karewa deposits sweep over the Pir Panjal range with dips which in places reach 50°. The latter observations have been confirmed by Dainelli.<sup>6</sup> De Terra<sup>7</sup> has recently given geological evidence that the uppermost topographic relief in the area between Kashmir and the Indus valley "has suffered from gentle warping, long after the Tertiary orogeny, and subsequent even to the intra-Pleistocene folding." Some of the recent earth movement in certain parts of the Himalaya seems to be the result of a continuation of horizontal pressure which produced the original region of high elevation, but some seems to be vertical uplift of a different sort. In Sikkim and the neighbouring parts of the Himalaya there is evidence that uplift to maintain approximate isostatic equilibrium during the development of the valleys is the cause of the upwarping and is responsible for the extra height of the Himalayan range above the plateau of Tibet. I have briefly stated elsewhere<sup>8</sup> that if the Sikkim part of the Himalaya were levelled by piling the tops of the mountains into the adjacent valleys, a plateau sloping gently towards the plain of the Ganges would result, and that the height of this plateau where the main range of the Himalaya now stands would be approximately 15,500 feet. It is significant that 15,500 feet is a little lower than the average height of that part of the plateau of Tibet which lies immediately to the north of Sikkim. In relation therefore to the isostatic balance of the crust the Himalayan range is here equivalent to the southward extension at a steadily declining height of the edge of the Tibetan plateau. It has been shown above that the Arun and Tista rivers must have originated on just such a surface. Here then is some evidence that maintenance of approximate isostatic balance during a period of erosion is the cause of the upwarping. The Eastern Himalaya as I visualize it have been produced in two distinct stages<sup>9</sup> and by two different processes. The first stage was the production by horizontal compression of an elevated plateau in approximate

<sup>1</sup> Nansen, F., "The Earth's crust, its surface-forms and isostatic adjustment." *Norske Videnskaps-Akademi*, 1 Oslo 1 Mat. *Natur.*, Klasse 1927, No. 12, 1928, pp. 1-21.

<sup>2</sup> Jeffreys, H., *Gerlands Beitrage zur Geophysik Bd. XVIII Heft, 1/2, 1927*, pp. 17-18.

<sup>3</sup> Garwood, in D. W. Freshfield's 'Round Kangchenjunga,' has given other evidence for vertical uplift and tentatively suggested that isostatic uplift consequent on shrinkage of the glaciers of the region was the cause.

<sup>4</sup> *Mem. Geol. Surv. India*, vol. XXIV, Pt. 2, pp. 59-142, 1891.

<sup>5</sup> *Mem. Geol. Surv. India*, vol. XLIV, p. 241, 1923.

<sup>6</sup> See E. G. Garwood's review. *Geogr. J.* 63 (1924) 243-6.

<sup>7</sup> H. de Terra, *Mem. Connecticut Acad. Surveys*, vol. VIII, p. 67.

<sup>8</sup> *Nature*, vol. 132, p. 28, 1933; and 'Everest 1933,' pp. 328-31.

<sup>9</sup> This conclusion I have stated before ('Everest 1933,' pp. 330-31). De Terra has recently given other evidence for the same view (*op. cit.*, p. 71.)

isostatic equilibrium. This plateau is essentially the present plateau of Tibet, but when formed it extended farther south over the region which is now the Himalaya. The second stage, which is presumably still going on, is one of vertical upwarping of the edge of the plateau to maintain approximate isostatic balance as the rivers cut deeper and deeper valleys into its edge. The second stage is the one which has produced the extra height of the Himalayan mountains above the plateau of Tibet. In the Eastern Himalaya, without the deep valleys and gorges, it is probable that there would have been no peaks towering 10,000 feet above the plateau of Tibet.

### THE BRITISH GRAHAM LAND EXPEDITION, 1934-37

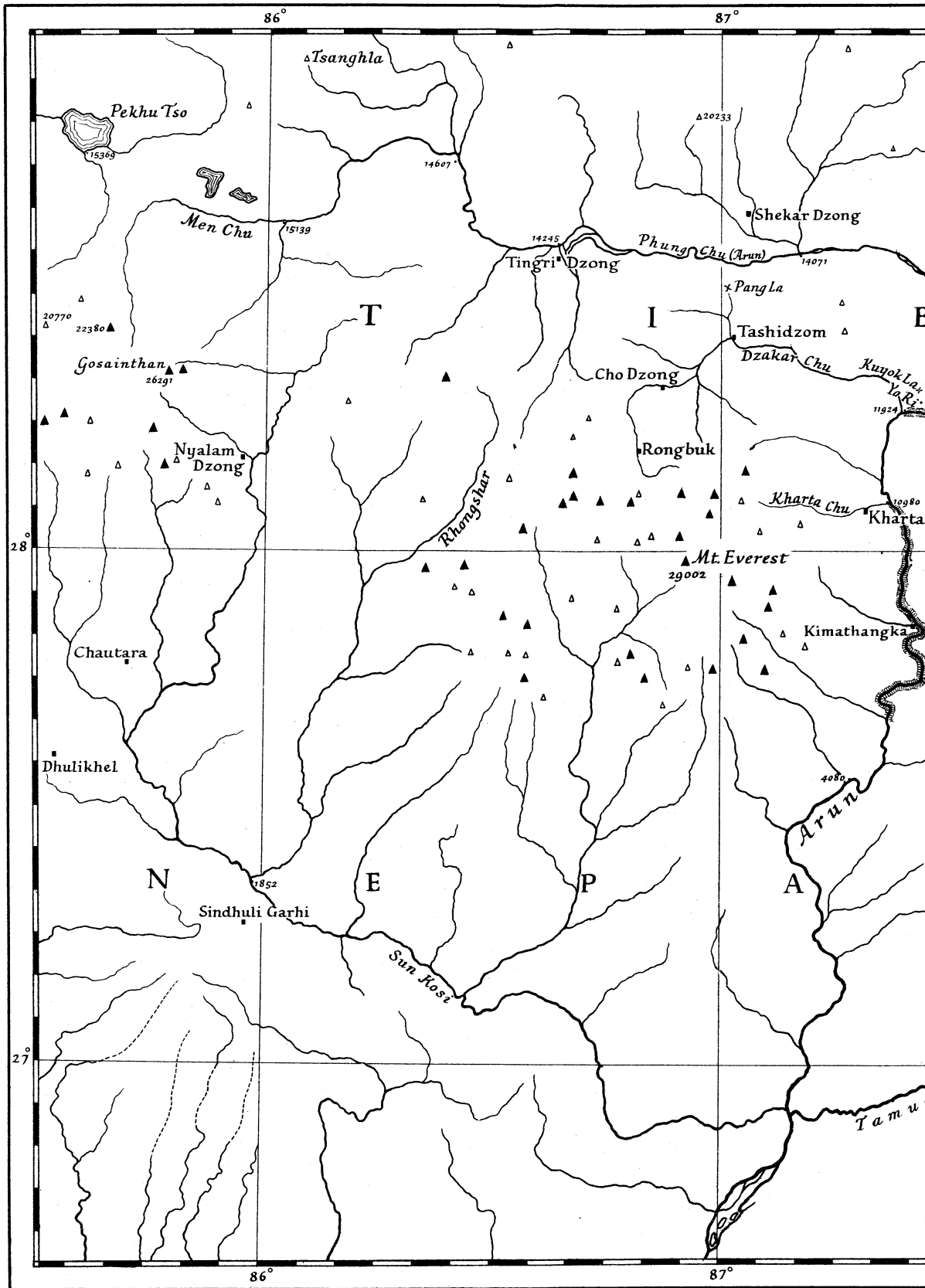
SINCE the work of the British Graham Land Expedition was last summarized in the August number of the *Journal*, a whole season's sledging has shown that the lower third of the map published with that summary must be radically altered. Before the flight of Sir Hubert Wilkins in December 1928, Graham Land was thought to be a long peninsula of the main continent. The indications of the photographs and observations from that flight were that the peninsula was an archipelago with at least three channels cutting through it, which were named Crane Channel, Casey Channel, and Stefansson Strait, from north to south respectively. The existence of the two southern channels is now disproved, and much doubt is cast on that of Crane Channel. The work of one Australian, Rymill, has undone the work of another, and it must be admitted that photographs from the air under the conditions of a long and hazardous flight may lead to entirely erroneous conclusions. Until the expedition returns with its detailed surveys it is impossible to estimate how great the changes in the map will be, but it seems likely that Stefansson Strait will have to be replaced by a fjord opening eastwards from a more or less ice-covered plateau up to 7000 feet in height, and that Alexander I Land must be magnified to at least five times its supposed size.

It will be remembered that the *Penola* left the shore party on Barry Island, at the north-eastern corner of Marguerite Bay, in March 1936. Rymill had with him at the base Bertram, Bingham, Fleming, Hampton, Meiklejohn, Moore, Riley, and Stephenson. The early winter (southern) of 1936 was spent in training the dog-teams for the projected sledge journeys, overhauling the equipment and fitting skis, instead of floats, to the plane. Blizzards at the beginning of May, the worst yet experienced by the expedition, delayed the formation of the sea-ice; the wind at its strongest reached a force of 110 m.p.h., and a hurricane force of 90 m.p.h. was recorded for several days, accompanied by low temperatures. By May 15 however the ice was bearing in most places, after a period of calm, cold weather, and nearly a month later it had reached a thickness of over 1½ feet. Conditions seemed to promise well for the spring sledging programme.

On June 9, in the uncertain winter twilight, Hampton, Rymill, and Fleming made a flight southwards after two trial trips, and saw, from a height of



# The Drainage Areas of



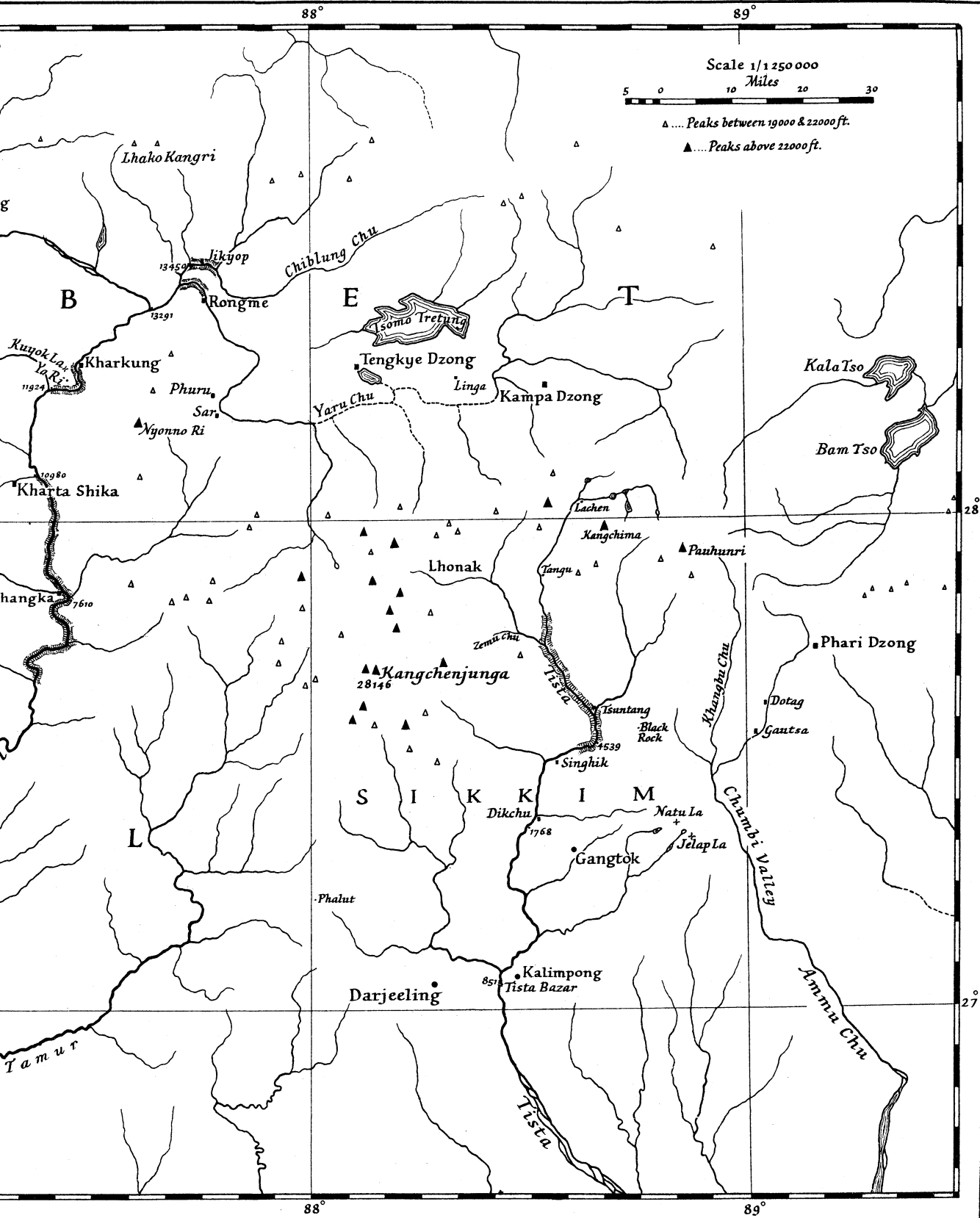
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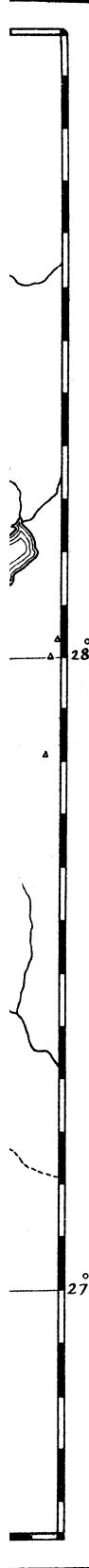
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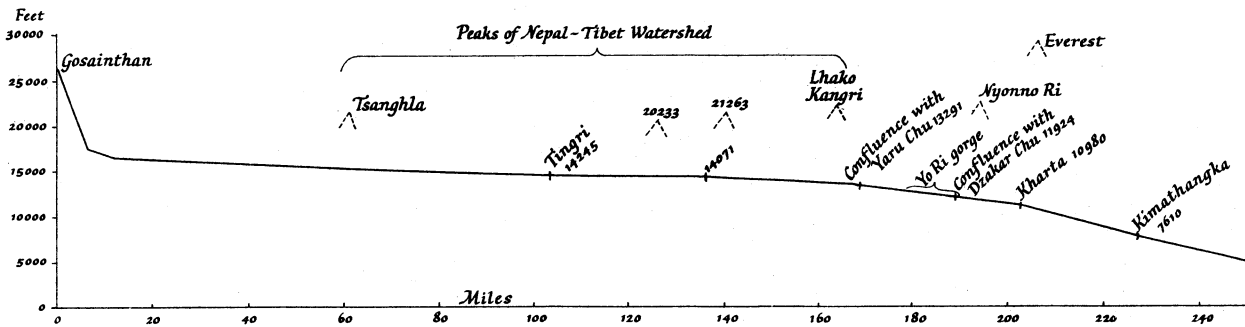
Peaks of Nepal-Tibet Watershed

Everest

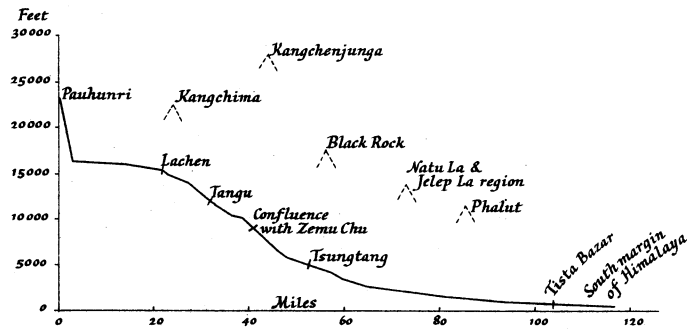
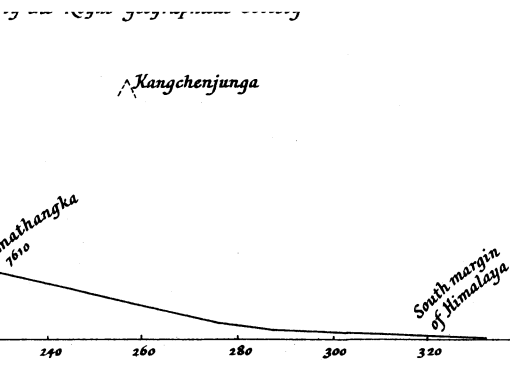


Larch, 1937





Profile of the Arun in Tibet and Nepal



*Profile of the Tista*

*The heights of certain peaks are indicated above the profiles where they are nearest to the valley*

**ARUN RIVER**  
*Wager*

*at  
the margin  
of  
Himalaya*

120

*RIVER  
Wager*