OBSERVATIONS ON THE ROCKS AND GLACIERS OF MOUNT EVEREST

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In April 1922 Dr. Heron read to this Society an admirable paper (Geo. Jour., vol. 59, No. 6), on the geological results of the first Expedition that he accompanied as official geologist. That paper gave an outline of his strenuous activities in the area lying to the north of Mount Everest, and his work was, as he himself has said, "virtually a continuation to the westward of Sir Henry Hayden's pioneer investigations during the Tibet Expedition of 1903-4." Heron's work was largely concerned with the sedimentary rocks that comprise the area to the north of the great belt of crystalline rocks developed along the main axis of the Himalaya. Time did not permit of his making more than brief flying visits, so to speak, to the crystalline zone, and he had hoped, on the next expedition, to study the crystalline area in detail. However, in 1922 and again in 1924 political objections were raised to the presence of an officer of the Geological Survey of India, and so the opportunity of much valuable work on the great problems of the uplift of the Himalayas, in a region hitherto inaccessible, had to be sacrificed. I was merely a member of the climbing party and oxygen officer. But it could hardly be expected that a geologist by profession, however occupied with the numerous other duties appertaining to the expedition, would keep his eyes closed to all the features of the landscape for the five months during which the expedition lasted. And it is the results of those observations and a few of the conclusions drawn therefrom that I propose to put before you. The paucity of the results I am only too well aware of, but preoccupation with the oxygen apparatus for use on the mountain, which necessitated continual work on it during the whole of the outward journey, as well as the time spent in the attempts on the summit, and all that this primary object of the expedition involved, quite prevented much detailed observation.
OBSERVATIONS ON THE ROCKS AND

PART I. THE ROCKS.

I propose at the outset to skip over any observations I may have to record on the younger sedimentary rocks, of which the vast elevated plateau of Tibet is predominantly formed. I have scarcely anything to add to the work of Sir Henry Hayden and Dr. Heron on these formations. My observations are principally confined to the crystalline and metamorphic zone of the main chain of the Himalayas and their associated rocks, the so-called "Metamorphic Complex," and may be considered as supplementary to those made by Dr. Heron more especially up to the northern border of this zone. I was able to penetrate well into this zone in two localities in particular, that in the neighbourhood of Mount Everest itself, and that of the Rongshar and Gaurisankar about 40 miles to the west. But in neither case had I the opportunity of extending my investigations very far laterally, that is to say, east and west of these southward lines.

The Mount Everest Region.

In trekking southward from the town of Shekar Dzong en route to Mount Everest, the crystalline rocks first make their appearance in the valley of the Dzakar Chu at the point where the Gyachung Chu comes in from the west. The path to Rongbuk leads along on the true right bank of the Dzakar Chu, and apart from an interesting occurrence above the Chöbu monastery recorded by Heron, one first strikes the main mass of the crystallines at the above river junction in a great cliff overlooking it on the eastern side. It is composed of dark horizontally banded biotite gneiss alternating with bands of light granite, though in the upper part of the cliff the latter is represented by pegmatite, and the whole appears to represent a large-scale example of "lit-par-lit" injection. The section showed a predominance of gneiss towards the top of the cliff. The gneiss itself shows an alternation of biotitic and felspathic bands, and this strongly foliated type is essentially non-porphyritic. The important question of the relation of this crystalline mass to the limestones that rest on it near the summit of the bluff will be dealt with later.

As one proceeds up the wide valley of the upper Dzakar Chu past the village of Rongbuk this same strikingly banded series continues on either side, often forming steep cliffs, especially on the east side of the valley, with inevitable talus slopes at their foot. Near Za-Rongbuk is a section close to the path showing clearly the biotite gneiss invaded and cut clean across by bands of pegmatite, indicating the younger age of the latter.

A far-flung head-tributary of the Dzakar Chu enters the main valley from the east not far from the snout of the Rongbuk Glacier, and here in the gorge it has excavated I found a most interesting section through the banded gneiss and its associated rocks. Persisting in its horizontality for the most part, the former was again seen to be intimately mixed up with the light granite, which invaded it both along the planes of foliation.
and also right across them. This granite was pinkish in colour, contained tourmaline and garnet, and being poor in white mica frequently graded off into pegmatite. The biotite gneiss also was here notably garnetiferous. Isolated lenticles of the pegmatite within the gneiss were sometimes apparent, and that the whole had been reduced to a state of fluxion at some time in its history was evidenced by veinlets of the biotitic rock running off into the pegmatite. The gneiss on the whole had only local contortions, but at one point in the gorge a fault block had been turned through 90°. Higher up in the gorge occurred a very coarse porphyritic granite or pegmatite with large phenocrysts of muscovite and tourmaline, often 2 or 3 inches across. Resting on the latter was a large mass of hard green variegated limestone, thoroughly crystalline, containing much epidote where the pegmatite had invaded it. The relation of these limestones to the overlying gneisses was unfortunately obscured by slopes of scree. In this gorge, which I tentatively dubbed the "Hermit's Gorge," owing to the existence of a lama's retreat near its entrance, I was also interested to find pebbles of grey limestone, evidently washed down from the parent bed (Permo-Trias?) away to the east, but time did not admit of my ascertaining this.

Another locality that was examined in some detail was the steep face overlooking Camp I. on the north by the snout of the East Rongbuk Glacier. Here was again found thoroughly metamorphosed and crystalline limestone resting on the schorl granite, which sent off apophyses into it. Above the limestone, which had perhaps an apparent thickness of about 100 feet, was the banded biotite gneiss associated with other metamorphic rocks appearing conformable upon the limestone, and looking more than ever like a bedded sedimentary series.

The same succession extends southward to the head of the East Rongbuk Glacier, giving the impression of a practically undisturbed stratified series. Near Camp III. an exposure at the end of the eastern spur of Changtse showed the same metamorphic series, though without the limestone, garnetiferous biotite schist being predominant, and the whole mass permeated with pegmatite. Southward across the névé basin of the East Rongbuk Glacier the series appears to continue in the lower part of the north-east ridge of Mount Everest itself, and the marked junction it makes with the overlying banded biotite gneiss is nowhere better seen perhaps than from Camp III., though bad weather and snow-covered rocks prevented my examining this junction in detail. A noted fault and anticlinal flexure of the beds is seen also from here.

The rocks of the North Col vary from dark very fine-grained biotite gneisses to hornblende and tourmaline rocks, dipping northward at 29° to 30°. As one proceeds up the north ridge of Mount Everest the rocks change from the more silicious varieties found below to others decidedly calcareous in composition. At about 24,000 feet there was some slight evidence of an unconformable junction between the silicious
and calcareous facies, but owing to the rolling of the beds and the general dip outwards (i.e. north) of approximately 30°, the gradient of the ridge itself being here about 35° to 40°, together with the extensive screes, it was impossible to determine this precisely. It is of course this particular characteristic of the north face of Mount Everest, namely, the outward sloping overlapping slabs with their numerous "reversed scarp" faces, that makes the ascent so awkward, though not strictly difficult. The rocks moreover are not on the whole rotten, since they have been considerably indurated.

I do not propose here to describe in detail all the petrographical types met with in the upper part of the mountain: suffice it to say that they consist predominantly of dark calc gneisses, light limestones, and sandstones. Specimens brought back in 1922 by the high-climbing parties and examined by Dr. Heron, were diagnosed by him to be calc-silicate rocks for the most part, but unfortunately he was led badly astray in regard to one important zone. I refer to the light brown band of rock that extends so prominently from the north-east shoulder right along into the base of the final pyramid. Geologists should be the last people to depreciate assistance rendered by amateurs. Nevertheless the latter are apt to lead one astray in such matters as the exact localities at which material has been collected, and especially in regard to the predominance, or fortuitous occurrence, of any specimens collected. The party that reached the above light band of rock in 1922, brought back a specimen from it that Heron examined and found to be a schorl moscovite granite. I reached this belt of rock myself last year and found it to be undoubtedly formed of calcareous sandstone, which incidentally is at times micaceous. Now the whole metamorphic series of which Mount Everest is composed is intruded by the light schorl granite and pegmatite, which breaks across the bedded rocks in conspicuous dykes and veins here and there, having come up through the subjacent biotite gneiss. This intrusive granitoid rock is very insignificant in amount relatively to the sediments, and occurs quite fortuitously. The simple explanation of the anomalous find of 1922 is that if it were definitely made at this light belt of rock at over 27,000 feet, it was plucked from a chance occurrence of the granitoid rock within the sandstone. Consequently, I fear the view expressed by Dr. Heron that this supposed sill of hard granite is the main factor in preserving the prominent north-east shoulder, as well presumably as the main peak, is no longer valid.

The final pyramid of the mountain is composed of a dark calc schist containing quartz and biotite, very fine grained and compact, which extends also some distance along the north-east shoulder as a cap rock to the above-mentioned sandstone, and this may in some degree be contributory to the pre-eminence of Mount Everest. But, in my opinion, other and more cogent factors, causes predominantly tectonic, must be
WEATHERED STACK OF BANDED GNEISS AND GRANITE, ALSO OLD MORAINE TERRACES ON FURTHER SIDE: RONGBUK VALLEY

DARK BIOTITE GNEISS WITH INTRUSIVE VEINS OF WHITE PEGMATITE: ZA-RONGBUK

BANDED GNEISS (DARK) AND GRANITE (LIGHT) RONGBUK VALLEY
BIOTITE GNEISSES RESTING ON LOWER CALCAREOUS SERIES (LIGHT): CAMP I.

CLIFFS OF THE NORTH-EAST SHOULDER OF MOUNT EVEREST, SHOWING DISLOCATION AND FLEXURE OF BEDDED BIOTITE SERIES
GLACIERS OF MOUNT EVEREST

sought for a full explanation of this pre-eminence. The extra height of the final pyramid, however, would appear to be due to a fault of small throw bounding its eastern side, the line of which marks the pronounced couloir that was reached by Norton on the occasion of his recent ascent.

Looking from high up on the north face of Mount Everest, I had the opportunity in intervals of good weather—which when I was there were all too infrequent—to observe the continuation of the Everest sedimentary series northward in the North Peak (Changtse). The upper part of the latter is obviously composed of the Everest calcareous series, resting on the bedded biotite gneiss, profusely veined with the light pegmatites. The junction of the two series is most marked, owing to the colour difference, and is straight and regular. This is vividly shown in Somervell's wonderful photograph taken from 28,000 feet, where one is looking down the dip-slope of the series. The true nature of this important junction it is difficult to tell, but it has the appearance of being a disconformable one, though one is apt to be deceived by the foliation as well as by the irregular veins and sills of pegmatite, which however are mostly confined to the dark gneiss below. The further extent of the upper calcareous series is seen in the upper parts of the higher peaks, such as Khartaphu to the north-east, and probably Gyachung Kang to the north-west; but the lower peaks are mostly of the lower biotite series, the prominence of many, no doubt, being partly due to their being fortified by the intrusive granites and pegmatites.

The marked extension almost horizontally of the west ridge of Mount Everest itself is due similarly to its being composed of the more resistant biotite gneisses, the softer overlying calcareous rocks having been here eroded away.

In the region of the West Rongbuk Glacier, which was visited by Hazard to extend the topographical survey, I understand there are representatives of most of the afore-mentioned metamorphic rocks, and these are in their expected positions relative to one another.

The Rongshar Region.

The Kyebrak glacier, which flows northward between the lofty Cho Uyo and Cho Rapsang, occupies a valley which in its lower part is bordered by cliffs of the same series of banded biotite gneisses as exist in the Rongbuk valley. Beneath these I found at several places the same metamorphosed sediments, in particular limestone, as obtained below the banded gneisses of the Rongbuk. These series were all well veined with pegmatites. In the neighbourhood of the Phusi La, that leads over into the Rongshar Valley at an altitude of just over 17,000 feet, I found unmistakable representatives of the upper Everest calc gneisses. These I first identified in the northern spurs of Pt. 18620, which is a northern outlier of Cho Rapsang, and saw that they also extended all
along the top of the range bordering the west side of the Kyebrak glacier, both north and south of the Phusi La. I also found cliffs of limestone and calc-gneiss well over on the southern side of the pass. These were succeeded below, as was to be expected, by the banded biotite gneiss series. In dropping down the upper part of the Rongshar, my notes record a gradual change from the horizontally banded and foliated gneiss of the northern side of the range to the much more knotted and contorted gneiss that extended throughout the lower parts of the gorge. This latter gneiss was recognizable of course as the typical Himalayan "Augen Gneiss" that forms the core of the whole extent of the range, and which has been so often described from numerous localities. It is almost unnecessary for me to repeat here that its truly intrusive character was long ago proved by the late Gen. C. A. McMahon.* Both in texture and structure the contrast between this augen gneiss and the intensely foliated biotite gneiss could hardly be greater, though I cannot here go into the essential points of difference.

The junction and relationship of the two in the upper Rongshar I was unable to determine with any precision, either owing to inaccessibility or the obstruction of talus and moraine, but it would certainly appear that the augen variety were the younger and intrusive facies. I might mention that Heron, from what he saw in the Kharta valley and elsewhere, was obliged to leave the question of relationship undetermined. In the lower Rongshar the general dip of the augen gneiss appeared to be from 25° to 30° North, and this persisted right into Nepalese territory. Near Tasang and lower down at Chuphar appeared schists and other metamorphic rocks, including limestones—one more link, can we say, in the chain of evidence for an ancient sedimentary series, that may represent, as Hayden and others have supposed, a distant "inlier" of one or other of the Archean systems of the Indian Peninsula. Throughout the Rongshar region the typical schorl granite was again seen with its associated pegmatite, cutting across everything and exhibiting in places such extreme fluidity that parts of the gneiss into which it had been intruded were floated off during its injection.

Prof. Garwood, during his classic journey with Dr. Freshfield round Kangchenjunga,† was not able to find definite evidence that the pegmatites of that region were younger in age than the Himalayan gneiss, but thought that the former might be apophyses of the gneiss. In the Rongshar to the west, at any rate, the relation is unmistakable; that the pegmatites are the younger, though probably not by very much, since at places broad bands of pegmatite lie "bedded" almost horizontally with the augen gneiss, and give the appearance of having been rolled out with the gneiss during movements subsequent to the latest intrusions.

† Garwood in 'Round Kangchenjunga,' D. W. Freshfield p. 292.
As to the structure of Gaurisankar itself, I was never able to see it sufficiently clear of cloud or snow to be able to make out the nature of its upper part, but its lower rocks appeared to be of typical Himalayan ortho-gneiss much fortified with pegmatite dykes.

**Permo-Trias Limestones.**

Before attempting to base any conclusions upon the similar metamorphic suites of rocks of the two districts visited and described above, I propose to deal briefly with the series of limestones that Dr. Heron found running along the southern border of the vast extent of Jurassic shales of the Tibetan Plateau, and which are wedged in at places between these folded shales and the metamorphic rocks of the crystalline complex. These were found by Heron to be a uniform assemblage of unfossiliferous limestones with shaley partings, all fossils having been destroyed and now appearing supposedly as streaks of crystalline calcite. But in one locality a prolific fossil fauna of Productus and Spirifer was found, indicating a probable Upper Permian age for the limestones. The Jurassic shales appeared to be lying conformably on these limestones. Now Hayden was of opinion, from his researches in the country to the east, that the Jurassic shales represent the upper part only of that system and are the equivalents of the Spiti Shales, and that the lower (Lias) beds, as evidenced around Phari in particular, consist of various slates, quartzites, and limestones, the lowest of all being a brachiopod limestone, whose fauna indicated either Liassic or possibly Rhaetic age.

Professor Garwood found an interesting crinoid limestone in Lhonak on the northern border of Sikkim, which in spite of earlier faunistic difficulties Hayden has shown to be very probably Jurassic; these difficulties, incidentally, were on account of its apparent equivalence to the crinoidal limestone found by Sir Joseph Hooker on the north-eastern border of Sikkim, and thought by him to contain nummulites and to be therefore Tertiary in age.

But Hayden has shown the fallacy of this, and the extreme probability of its also being Jurassic and in particular Liassic. All these fossiliferous limestones along the northern border of Sikkim appear therefore to be coëval, and it is not until we get into the region of the Dzakar Chu to the west, where Heron found his Permian or Lower Trias limestone in a corresponding position with regard to the crystalline rocks, that difficulties of correlation arise. Briefly, it would appear that if the Upper Jurassic (Spiti) shales are resting upon the productus limestone, then a large series of rocks, referred by Hayden to the Oolite and Lias stages, has been cut out, although Heron at this point says the shales seem to rest normally on the limestones. The point is of interest, since to the west of the Dzakar Chu and extending much further west beyond the Lamna La, I found a large series of limestones overlapping on to the crystallines to the south and brought up against the shales on the northern
side. These hard, dark grey limestones, weathering reddish-brown, were quite unfossiliferous and seamed throughout with calcite. Owing to their lithological resemblance and position, I took them at once to be the westward extension along the strike of Heron's Permo-Trias series, though in this locality he had mapped the occurrence of Jurassic only. Looking east across the Dzakar Chu one could make out by colour contrast their certain continuation into the area actually mapped as Permo-Trias. Now associated with these limestones near the Lamna La I found ferruginous quartzite, conglomerate, and the ever ubiquitous shales, and it would seem that the association of these zones with the limestone would place the series on a par with Hayden's succession for the Jurassic in the Kampa and Phari regions, or at any rate with a good part of that succession. Certain beds of the succession of Lamna La seem to be missing, but there is considerable evidence of strike faulting which would explain this. While the limestone series here is so completely barren of fauna and calcitized and cannot be compared with the highly fossiliferous beds near Kampa, yet the character of the former may be entirely due to its proximity to the hard crystalline rocks and its alteration brought about by pressure against them, if not also by their igneous intrusives. At the same time it is equally possible that the same strike faulting and probable overthrusting, along the line of the Dzakar Chu and Lamna La may have cut out some of the limestone and other zones of the Lower Jurassic, and have caused the Permo-Trias limestone, continued westward beyond the Lamna La, to be thrown against the Upper Jurassic shales. On two occasions, once by a flooded river and another time by a feeble pony, I was prevented from reaching Heron's type areas of the Permo-Trias limestone and so comparing their stratigraphical relationship and character with those of the limestones I found east and west of the Lamna La.

But whether this limestone be referred to the Permo-Trias or to the Jurassic System, I noticed that it appeared to be strikingly unconformable to the banded biotite gneisses of the Metamorphic Complex on to which it transgressed. At the top of the cliff overlooking the confluence of the Dzakar Chu and the Gyachung Chu mentioned earlier, it was seen that the limestone seemed to transgress the bedded biotite gneiss, but the flooded state of the river unfortunately prevented my crossing to it and ascertaining the true nature of the junction. It is quite possible, on the other hand, considering the overfolded character of the sedimentary beds to the north that this is really the faulted junction of a thrust plane.

Conclusions regarding Stratigraphy of Mount Everest and Rongshar Regions.

Some attempt will now be made to synthesize the information gleaned from the above localities and construct a stratigraphical picture of the whole region.

For many years controversy has raged around the true origin of the
Himalayan Gneiss, the "Central Gneiss" as it was once called, as to whether it were an intrusive igneous rock, or whether it represented an extreme stage in the metamorphism of ancient sediments; whether, in other words, it were an "ortho-gneiss" or a "para-gneiss" respectively. Reference has earlier been made to General McMahon's work in proving that it, or at any rate a large part of it, represents an ortho-gneiss. Mr. R. D. Oldham has shown that it may be almost impossible to distinguish even microscopically the gneiss that was once a sediment from that truly an intrusive granite, and that field relations must be the chief factor in determination.

When I first reached the Mount Everest region I took the banded biotite gneisses, so prevalent there, as unquestionably intrusive in character. It seemed to be only one more example of the great lateral extent to which intrusive rocks can travel in sills of nearly constant thickness. It seemed possible, though, that this might have been emphasized subsequently by overthrusting and rolling out of the beds upon one another as suggested by Heron. But my investigations, brief and incomplete as they were, have brought me more and more to the view that this particular series of banded biotite gneisses represents in actuality a highly metamorphosed series of sediments probably argillaceous and arenaceous in general character. Disregarding their strikingly bedded appearance, which is mainly due to the wholesale injection of pegmatite along foliation planes, their regular position between the upper and the lower calcareous series throughout the Mount Everest and Rongshar regions, and the absence of any evidence of apophyses running off into these series, seem to indicate with a fair amount of probability that they are of sedimentary origin. The difference between this biotitic felspathic gneiss, often garnetiferous, and the augen gneiss of the deeper core of the range has already been remarked. I could find no occurrence of the latter in the Rongbuk district, nor indeed on the northern side of the main range.

As to the upper calcareous series that forms the calc gneisses and calc schists of Everest and also those of Kyebrak, they would appear to be the natural outlying extensions to the south of the so-called Permo-Trias limestone series, and their metamorphosed condition due to their being in the zone of maximum stress. If the upper calcareous series and the bedded gneissose series be definitely proved by future work in the region to be stages of a single sedimentary series, or separate ones not far removed in time, it may be possible (and their position suggests it) to link them up with Hayden's Dothak (Lilang) series of Phari, which has comparable lithological zones, though less metamorphosed.

The lower calcareous series, completely recrystallized to marbles, slates, schists, etc., that is only found beneath the bedded gneiss, would appear by its position and advanced state of alteration to be a much older series. Those exposures on the Tibetan side may conceivably be
referred to Hayden's Khongbu Series of undoubted Pre-Jurassic and probably very much older Purana age, found also near Phari; while the lithologically similar assemblages found deep down in the Rongshar may be analogous to the Mallet's Daling Series of Sikkim or the Baxa Series of Southern Bhutan. But these are only suggestions, and much further work must be done before such correlations can be safely made.

I must mention that in my reading of the structure of this region I have endeavoured to avoid the invocation of elaborate movements or even of extensive overthrusting. Overfolding and complicated dislocations without doubt there are in the area of the younger and more yielding Tibetan sediments, but on the northern borders of the main range the more compact and indurated rocks are strikingly free from much appearance of lateral thrust. I sought in vain for real evidence of an overthrust and only at the junction of the Liassic (or Permo-Trias) limestone with the banded gneisses in the Dzakar Chu, already cited, was I able to recognize such a possibility. The complicated nappes and decken movements of the Alps do not appear to have afflicted the Eastern Himalaya—at any rate as yet, and it is better, I think, to postulate rational, rather than irrational, quantities to elucidate problems on first acquaintance with a region.

But if evidence of lateral thrusting is meagre, it is not at all the case with vertical movements. On all hands throughout the small portion of the Tibetan side of the Central Himalaya I traversed, there is plain evidence of great vertical uplift. Chomolhari raises its head nearly 9000 feet abruptly from the Tibetan plain. Almost more impressive still is the great gneissose wall of Kanchenjhan and Chomoyumo in the north of Sikkim rising vertically out of the sediments of the Kampa plain. Many observers have of course seen ample signs of special elevatory forces, other than mere folding or intrusion alone, to give such prominence to this great sector of the Earth's crust, and it seems more than probable that the supremacy of Mount Everest itself, since we now know it to be in greater part of soluble calcareous rocks, must be largely due to vertical uplift in the past that may be continuing at the present time. It is not outside the bounds of possibility that the next climbing party may have a few more feet to go to reach the top!

The Kampa System and Jurassic Shales.

As mentioned earlier, I have very little to say in regard to the rocks of the Tibetan plateau, which date roughly from Jurassic to Eocene. The hurried outward and return journeys prevented more than passing observations, and these were mostly confirmatory of Heron's much more detailed work. The absence of the latter in India (I had only the opportunity of seeing him for half an hour in Edinburgh before he returned from leave last autumn) and our consequent inability to compare notes,
may detract somewhat from the value of the following short remarks on the above rocks, and modification may later be necessary.

On the return journey *via* Tingri I made an abortive attempt to reach the Permo-Trias area to the north and north-east of the sacred Lapche Kang Range. The pony that carried me paid far too much attention for my liking to her foal that accompanied us, and too little to the business in hand, and always tried to bite me whenever I suggested that we must be getting along; and indeed she was so far uninterested in the local geology as to once run right away, and I only caught her after a long chase by the dangling reins tripping her! In consequence I eventually only reached the neighbourhood of Kura at the south-western extremity of the vast Tingri plain. Coming from Sharto, south-south-west of Tingri; one skirted along the spur to the west that submerges itself at Shar in the alluvium of the plain. This seemed to be formed of dark sandy limestone weathering reddish, and it had a very slight northern dip. The hill against which Kura stood was of the same sandy limestone, dipping north, and forming with another outcrop across the valley, dipping south-by-west at 65°, an isoclinal anticline. No fossils could be found, but the writer knows of no arenaceous limestone of this character except within the Kampa System. Further south-west along the ridge, against this limestone anticline was faulted an anticline of dark shales with the steep limb to the north, and then followed a rusty limestone, the beds of which curved round to vertical, where they in turn were faulted against the steep limb of the shales. Subsequent folds revealed successively white calcareous sandstone, dark calcite-veined limestone, and reddish quartzite, that seemed to abut against the crystalline metamorphics without the intervention as far as could be seen of the Jurassic shales. The above sequence of folds could be roughly traced across the valley to the east in the shoulder running north to Shar, as already mentioned.

Now the hill behind Kura, as well as much of the rising ground beyond to the west, has been mapped in 1921 as alluvium, and this without doubt is a mistake. More important is the mapping of the sandy limestone at Shar as Jurassic, when it would appear, unless Heron found fossil evidence to the contrary, that this represents one of the typically similar limestones of the Kampa System. It would certainly seem that in these folded rocks at Shar and at Kura, as well as further west, we have at least some representatives of the Kampa Series. The ill representation of the Jurassic shales, if the above shale beds are in fact these at all, may be explained by the close folding and evident reverse faulting that have cut out no doubt a considerable proportion of known zones. The prevailing pressure from the north would seem here to have brought the Kampa beds right up against the Metamorphics, or otherwise regarded to have entrapped synclinally a Kampa outlier within the older folded Jurassic rocks.
OBSERVATIONS ON THE ROCKS AND

Lapche Kang (Munkri) Range and Gyankar Range.

The above-described locality, south-west of Tingri Dzong, is of considerable interest on account of its being at the north-eastern extremity of the great Lapche Kang Range, which, like the similar and parallel Gyankar Range 80 miles to the east, raises its jagged crest in a direction roughly transverse that of the general trend of the Himalayan ranges. To the writer the existence and strike of these two ranges are highly significant, and they appear to have had a marked effect upon the river-systems of the country, particularly in the case of the Gyankar Range. The latter was investigated by Dr. Heron in 1921, more especially in regard to the remarkable gorges through which the Yaru Chu and Arun make their way. The Gyankar and Lapche Kang Ranges are evidently not due to a transverse system of folding but to intrusions of granitic rock along these lines. Their relation to the geological structure and drainage of the region, apart from the direction they take across the strike of the main ranges, suggests that they have undoubtedly arisen subsequent to the latter. This assumption, at any rate, would help to explain the extraordinary deflection of the Yaru Chu east of Nyönee Ri and Sangkar Ri, which possibly had its continuity with the lower Arun interrupted by the range rising faster than the river could keep open its channel across this area, the formation in consequence of a lake, and final outlet through the Rongme Gorge to the north—a similar chain of processes that I believe Mr. C. C. Fox (Geographical Journal, vol. 59, No. 6, p. 433) has suggested for the remarkable lower gorge at Yö Ri. Dr. Heron has mentioned that at Yö Ri the river plunges into a gorge of hard gneiss, but I should like to have the actual formation here confirmed. If, as I suppose, both these ranges mark intrusions late in the scheme of events, then it is of interest to know whether they are not of the later granitoid rocks, i.e. the schorl granite, or the two-mica granite of the Northern Range that Heron found in a good many localities, or even, with some slight possibility, the hornblende granite that Hayden mapped in the neighbourhood of the Tsangpo. The concentration of intrusions of the two-mica granite in the Northern Range, particularly on the prolongation northward of the two lines of ranges, rather suggests that the latter may be genetically connected with them. Heron’s reference to the rock at Yö Ri being gneissose may be on account of local foliation at the time of its intrusion.

Dra and Ruli La.

Shebbeare and I, having crossed the Tse La southward to the Dzakar Chu, made great efforts on the return journey to reach Yö Ri in order to examine the problem of the latter’s gorge in particular, as well as the bigger problems of the uplift of the Gyankar Range and the relation of the Permo-Trias limestones to the Metamorphic Complex in that area. The Dzakar Chu was however hopelessly flooded, and we were quite
FLUVIO-GLACIAL TERRACES IN THE ARUN VALLEY ABOVE KHAIKHUNG, WITH MOUNT EVEREST IN BACKGROUND

OLD LATERAL MORAINES AND TERMINAL MOUNDS OF THE RONGBUK GLACIER, NEAR BASE CAMP
THE "TROUGH" OF THE EAST RONGBUK GLACIER, SHOWING VERTICAL VEIN-STRUCTURE OF ICE-WALLS AND PINNACLES

LOOKING DOWN RIGHT MARGIN OF THE "TROUGH," FROM ABOVE CAMP II.
unable to cross even as far up as Dra or make progress along the river gorge. We were obliged, therefore, to strike up into the hills from Dra in order to cross the Ruli La and so catch up our main party by forced marches to Tinki. This trek from Dra to Tsogo took us across a stretch of country apparently not previously visited, if one may judge by the variance between map and topography. Geologically this region has been mapped as Jurassic, and in greater part no doubt it is, but there is also ample evidence of Kampa System rocks squeezed in the tightly packed folds of the Jurassic. Our hurried march, however—not facilitated by a blizzard on the Ruli La at over 18,400 feet—prevented my mapping the actual extent of Kampa rocks in the neighbourhood.

**Synclinal Valleys.**

One of the very interesting discoveries that Dr. Heron made in the Tibetan area was the existence of rivers occupying synclines or structural basins, as opposed to the much more usual occurrence of anticlinal valleys, which structurally are so much weaker towards erosion. Though Dr. Pascoe has suggested a word of caution (*Geographical Journal*, vol. 59, No. 6, p. 436) in regard to the too hasty acceptance of these synclinal valleys, considering rather that the differential erosion resistance of the Cretaceous limestones and the other rocks may be the chief cause of these features, yet it would appear quite feasible in areas of such pronounced and abrupt overfolding, as has taken place along the line of the Phung Chu, for these to arise. I did notice, nevertheless, that near Kyishong, east of Shekar, the Phung Chu appeared most decidedly to occupy the deeply eroded axis of an anticline, both limbs of Kampa red arenaceous limestone dipping outwards into the hills on either side. And such an anticline in this particular locality would appear to be more consistent with Heron's own mapping, since just westward of this an anticlinal axis is indicated, which I was able to confirm on the ground. Also in the valley of the same river east of Tingri Gankar, in the neighbourhood of Memo, the limestones on either side seemed to dip steeply outwards, the channel occupying the broken crown of the arch, though there were in addition many minor folds in the steeply upturned limbs of the anticline. But apart from these two instances I was not able but to agree with Heron in his main contention that the Phung Chu does actually in parts of its course occupy synclinal valleys.

**Basic Igneous Rocks.**

The only occurrence of these I found was a pronounced dyke 6 or 7 miles south of Shekar, not far from the valley of the Phung Chu. It was a dark, much-decomposed rock that had been intruded along the strike of the very steeply dipping Jurassic shales, and these had been considerably baked in its vicinity. Later faulting had, however, pronouncedly affected the shales and the included dyke.
OBSERVATIONS ON THE ROCKS AND

No rocks of this description were observed nearer or within the zone of the Metamorphic Complex.

PART II. THE GLACIERS

The Mount Everest Massif has all the characteristics of a mountain region in an advanced state of glacial erosion and corrosion, whether we attribute the greater cause to the mechanical action of glaciers or to frost action. The long "through" glaciers, whose heads and tributaries have eaten their way back into the innermost recesses of the mountains to form innumerable cirques and corries, delimited by sinuous ridges and steep arêtes, all point to a state of nearly mature glacial denudation. But though the present length of the glaciers on the northern side of the range is considerable—the Rongbuk Glacier is about 11 miles—yet it is nothing compared with their former extent. On all hands it is evident that the glaciers of this region are shrinking back into the recesses where they have their birth. And this does not appear to be seasonal variation alone, but, in common with so many other glaciated regions of the world at the present time, a secular movement in a retrograde direction.

Take, for example, the valley of the Dzakar Chu. This long U-shaped valley bears all the signs, even in its lower parts, of having been sculptured directly and indirectly by glacial action, and banks of moraine attest to its former occupation by ice. In its upper parts above the Base Camp are conspicuous three systems of moraine shelves extending along the valley sides one above the other. They are especially noticeable on the west side, though the uppermost shelf at the foot of the crags is discontinuous owing to its being broken across at places by drainage from the corries. These morainic terraces far above the level of the present lateral moraines of the Rongbuk Glacier, can be said to correspond to periods of stagnation in the gradual retreat of the once enormously vaster glacier, since the maximum ice flood of the Glacial Cycle. That the Rongbuk Glacier has halted at times in its retreat is also borne out in an interesting way by the large mounds of terminal moraine that it has dumped at intervals in the bed of the valley, the greater segregations being separated by areas relatively clear and level. Our Base Camp was situated on one such collection of mounds, and for nearly ¾ mile ahead of this was an even plain, levelled no doubt to some extent by the outwash from the glacier, right up to the present moraine-covered snout. Other evidence of progressive retreat is to be found at the termination of the East Rongbuk Glacier, which has shrunk back nearly a mile from its former confluence with the main Rongbuk Glacier.

Evidence of three separate periods of glacial extension has been discovered by Oldham in Kashmir, and similar oscillations have been observed by Huntingdon in the Pangong valley of Ladak, but it would be altogether premature at this juncture to suggest correlation between these and the movements of the Mount Everest glaciers so far to the east.
Conditions at the North Col.

In the mind of the writer a particular and somewhat peculiar local case of this wholesale waning of glaciation is to be seen at the North Col, between the peak of Mount Everest and Changtse. Here is a col at 23,000 feet piled up in the most impressive and weirdest way with gigantic blocks of ice, their sides clean cut for the most part, seeming to be the disrupted fragments of a much greater mass of ice that once capped the col. The eastern slopes of the col, up which lay our regular route, consisted of hard névé at an average angle of about 35°, broken at intervals by schrunds and ice facets. The western face towards the West Rongbuk Glacier is mostly of steep ice-slopes. Now, in this high country with such evident signs on all sides of slight precipitation, and probably increasingly so, it is extremely difficult to see how the present snowfall is sufficient to give this enormous accumulation of ice on the eastern side and maintain it constant in such vast amount and in such a position. And if it were so, it seems incompatible indeed with the occurrence of the great disrupted blocks of well-consolidated ice on the top of the col, which under normal conditions of annual precipitation would be speedily submerged and formed into a regular and continuous cornice. Col. Norton, on the other hand, considers that the present snowfall, concentrated on convergent lines into the funnel that the North Col forms, is probably sufficient to explain the amount of the ice present, though he admits the difficulty in this view of explaining the well-consolidated cut-up blocks at the top. In my opinion this great ice mass in all probability represents the lingering remains of a once greater amount that may have been more uninterruptedly continuous with the East Rongbuk Glacier when the latter at an earlier period filled its basin to a higher level: in other words, it may be described as a relic of the past—a mass of "fossil névé."

Motion of the Glaciers.

The northern side of the Great Himalaya is a region that exists in, and is subjected to, a set of physical conditions unique probably in the world, and the effects of these conditions on its glaciers are correspondingly great. Low mean annual temperature, extreme dryness, great altitude, together with a tropical sun, must be expected to produce marked results, quite different from other effects in glaciated regions of more temperate climate and of other latitudes. In many of the phenomena I was reminded of the Arctic, the glaciers of Spitsbergen in certain respects exhibiting comparable features. Owing to low mean temperature the ice of these Mount Everest glaciers must be proportionately low in temperature, and this will mean that it has a correspondingly higher degree of rigidity or viscosity, whatever may be our views as to the ultimate structure of glacier ice in general and its mode of flow. Mostly the ice is of a very coarse texture, the granules being on the whole about the size of walnuts, a
condition in which they simulate Arctic glaciers more than they do Alpine. On account of the rigidity of the ice the motion of the glaciers will be slow. Somervell and I endeavoured to estimate the rate of flow of the East Rongbuk Glacier by the motion of one of the pinnacles well out in the ice-stream. In ten days we found it had moved only about 2.5 feet, equivalent to 3 inches per day. Such observations as have been made on the motion of Himalayan Glaciers on the southern side and at the north-western end of the range, have given a diurnal motion of 3 to 5 inches at the side, and 8 to 12 inches in the middle.* Though our observation was an isolated one in the lower part of the glacier and but roughly undertaken, it seems to indicate a relatively slow rate of movement for these glaciers, such as would be expected. But though the velocity be low it must not be supposed that the erosion of their beds by the glaciers will be correspondingly less, for the extra rigidity of the ice will hold stones in the base of the glaciers with increased firmness and abrade the bottom with greater force. The gigantic moraines of these Mount Everest glaciers are evidence enough of the destruction wrought mechanically by the motion of the glaciers, apart from that brought about by the agency of frost action.

Length and Minimum Altitude of Glaciers.

The present lengths of the glaciers of the Mount Everest region compare fairly favourably with those of other parts of the Himalaya, and are only notably exceeded by the immense "longitudinal" ice-streams of the Karakorum. The Rongbuk Glacier system has a greatest length of about 12 miles, and the snout is at an altitude of nearly 16,500 feet; while the Kyebrek Glacier is nearly 11 miles in length and descends to about 15,400 feet. These are the two principal mapped glaciers on the northern side of the main axis, and typify the "transverse" glacier, that is one flowing down a valley at right angles to the range. Elsewhere in the Himalaya the latter never attain the size of the longitudinal type, which occupy troughs between the ranges. The only mapped representative of the longitudinal variety is the Kangshung Glacier on the northern side of the Makalu Group, which has an approximate length of 12 miles, and whose snout is at 14,600 feet above sea-level. As an eastward-flowing glacier it is comparable to the Zemu Glacier of the Kangchenjunga Group, which however has a length of 16 miles and descends to 13,900 feet. That none of these figures for the minimum altitude reached by the glaciers is as low as those of the north-western end of the range is probably chiefly on account of the lower latitude, though other factors of local situation, supply, and gradient must always be taken into account. The glaciers of Kumaon and Lahoul have a lower limit of 12,000 feet, while those of Kashmir descend to about 8000 feet in some cases.†

* D. N. Wadia, 'The Geology of India,' p. 15.
† Ibid., p. 14.
Wastage Effects.

In spite of the low mean annual temperature from which this region suffers, its situation in such a low latitude (28° N.) causes it to experience the effects of a very hot sun. On the North Col at 23,000 feet on more than one occasion when I took temperatures at midday, the air temperature was 29° F. whilst the sun temperature at the same time was 105°. In such a degree of heat with a high-pitched sun melting effects on the glaciers and snowfields are immense, though actually the visible melting is surprisingly little, the high evaporation under such low atmospheric pressure causing the solid forms of water to pass direct into vapour without the intermediate liquid state. High up on the face of Mount Everest this is strikingly the case, and a considerable snowfall will in spring and summer have evaporated into thin air in a few hours without any visible melting. Consequently, and fortunately, "verglas" does not exist. On the glaciers the same condition holds in less degree, and it is only in their lower parts that streams of any size develop, and then not in our experience till the end of May. The intense ablation of the glacier surface gives rise, amongst other things, under these conditions to the remarkable ice pinnacles to be shortly described. And in spite of this ablation, and in contrast to the dirt-strewn glaciers of the north-western end of the Himalaya, these in the east and on the north side of the range are relatively clean. The Kangshung Glacier, however, on the southern side of the main axis shows in the photographs taken in 1921 a decidedly dirty surface due to mud or moraine. This may be owing to the even greater ablation that goes on on the warmer southern side; at the time these photographs were taken the monsoon was actually in progress.

On the other hand, it might be suggested that this effect is partly due to the deposition of dust borne on the prevailing winds from the plains of India, as has been claimed for the dirty state of the ice of the north-western glaciers, but since the prevailing winds at Mount Everest appear to be westerly this can hardly be maintained. In Spitsbergen, after a period of great ablation and thaw I have seen the glaciers appear quite black, and in that remote region dust deposition cannot obtain; on examination the incorporated dirt has proved to be highly comminuted mud derived from the rocks over which, or between which, the glaciers pass, which is concentrated by the action of thaw and ablation. The state of the Kangshung Glacier is, nevertheless, most probably brought about by the greater temperature variation of this south side, increased frost action, and consequent extra rock-waste from the surrounding cliffs, and from the south-east face of Mount Everest in particular, where the inward dip of the beds lays them open to special attack.

On the East Rongbuk Glacier were some rather beautiful examples of the so-called "cryoconite holes" or "dust wells," in which small particles of morainic material had melted their way down into the surface X
of the ice, as is so often to be seen on Arctic glaciers especially. Here, with the high altitude sun, the small stones and particles had melted their way very deeply down, and the wells becoming filled with water during a warm period it had later crystallized in a radial manner, and given the effect of round flower-like forms of clear ice within the surface of the glacier. The typical honeycombed ice of the Arctic was however not noted to any extent.

A striking example of the effects of a tropical sun is the way in which eastward and westward flowing glaciers frequently have their southern sides melted back into steep ice-cliffs, a case in point being the tributary to the East Rongbuk at Camp II., though others on the eastern flank of the latter were equally affected: this action is aided by re-radiation of heat from rock-walls enclosing the glacier.

An important factor in promoting ablation is the high wind, and we had no better example of its force than near the Base Camp. Here reinforced by sand, and impinging on blocks of granite, situated in gaps between moraine heaps, it was sufficient, blowing through these funnel-like gaps, to have grooved the blocks on their windward southern faces to a depth of an inch or more—long incisions across them independent of their mineral character and cutting across crystals of felspar and tourmaline alike. The sand-blast had been sufficiently intensive to have done its work since these morainic blocks were dropped by the glacier, now not much more than half a mile away.

A melting effect, which unfortunately I never had the opportunity to examine close at hand, is the conspicuous flutings on many of the peaks, particularly on their northern faces. The Lingtren Group of peaks at the junction of the main Rongbuk and West Rongbuk Glaciers are notable examples of this. Many travellers have no doubt considered such flutings elsewhere to be merely the result of a scoring and gouging of the face by falling cornices and avalanches, and the writer must admit that he had formerly rather subscribed to this view. But it is evident in numerous instances that the sharp ridges and arêtes above these fluted faces do not, nor ever have, supported sufficient snow or ice to gouge out by their fall such deep incisions. I could only conclude, from rather distant observation, that the flutings and ribs, which often extend in pronounced degree right up to the crests which support them, must be caused by a differential melting effect of the rays of the hot sun inclined obliquely to the face on which they act; though here again melting and consequent fluxion in the ordinary sense, owing to the high altitude and quick evaporation, is non-existent. I am not aware that the phenomenon is known, at any rate in such pronounced form, outside the Himalayan range, though it may possibly be seen in other high ranges of the tropics.
The Trough.

This interesting and possibly unique feature that provided a natural causeway for nearly 2 miles of the way up and down the East Rongbuk Glacier between Camps II. and III., will ever be remembered as a fairy scene, of the greatest beauty, by those privileged to use it as a highway to the precincts of the throne of the Great Goddess—Chomolungma. Imagine a corridor up to 50 feet deep and 100 feet wide with steep sides buttressed and pillared with fretted ice of exquisite tints of blue and white and green, and paved at intervals with the ice-covering of charming glacial lakelets, out of the surface of which were growing here and there clusters of ice-pinnacles, themselves sculptured into an infinity of forms. It was through scenery of this description that our way lay—exhilarating in the extreme, except at the hot hours of the day in late May and June, when the close stagnant air within the depression of the Trough was apt to produce a certain lassitude and disregard for its remarkable beauty!

The Trough, as a depression running longitudinally down the East Rongbuk Glacier, may be said to commence somewhere about the 20,000-foot contour of Major Wheeler's 1-inch map, and it continues uninterruptedly as far as the moraine-strewn lower end of the glacier. On first acquaintance I was at a loss to account for this remarkable feature. In early May the winter snow was still forming a practically continuous covering over the upper half of the East Rongbuk Glacier, and it was in consequence impossible to make any examination of the nature of the ice in the neighbourhood of the first pronounced depression. I noticed, however, that the snow seemed to be concealing a notable amount of ridging of the ice near the commencement of the Trough proper. It was not till later, when the new snow had evaporated sufficiently to reveal the underlying ice, that it was apparent that the latter exhibited plain evidence of severe stress. Here on the prolongation of the line of the Trough was a beautiful development of Forbes' "ribbon or vein structure"—clear blue bands of ice alternating with granular and more opaque air-filled varieties, the whole running parallel with the direction of motion of the glacier. It will be remembered that Forbes, who first described this "ribbon structure" during his classical researches on Alpine glaciers, showed it clearly to be a structure set up in ice in consequence of great compression and shear; in fact, it is precisely comparable to the foliation of rocks under like conditions of stress. Without following Forbes in extenso in his ideas of the true plastic character of ice and the consequent viscous flow of glaciers, developed partly around his discovery of the "ribbon structure," the writer has from his own observations in the Alps, Spitsbergen, and the Himalayas seen sufficient evidence to satisfy him that this banded "ribbon structure" in ice, usually seen vertically disposed, though by no means always so, is definitely and chiefly brought about by intense compression, such as at the junction of two convergent ice-streams, and is not to be confused, as some glacialists
have done, with the bedded structure of glacier ice due to seasonal ablation and deposition, or concentration of silt in layers within the ice.

That the ice above the Trough was undergoing severe stress was apparent not only from its foliation, but also from the faults—"flaws" or "tear-faults"—that had been extensively developed in this area, indicating that the ice was endeavouring to adjust itself to exterior forces; and where dislocation did not bring relief a ridging up of the ice was prevalent, as referred to above. At the commencement of the Trough itself the foliation bands seemed to have reached their greatest development, actual fusion of the ice taking place from the heat engendered by the compression, accompanied by simultaneous evaporation of the fused ice. And on this line of fused ice the depression of the Trough seemed to have developed, its walls displaying the banded structure in decided, though less pronounced, degree, and standing somewhat in relief above the general surface, on account, no doubt, of adjustment to stress.

Now the distance of the line of the Trough from the true left side of the glacier is about 400 yards, and coincident with it seems to be the medial moraine from the north-east shoulder of Mount Everest, carried englacially, for patches of moraine appear at intervals in the bed of the upper part of the Trough. Below the 19,750-foot contour it converges with the moraine coming from the north spur of Pt. 22,090, and this material largely carpets the continuation of the depression down the left centre of the lower glacier. The weathered walls of this lower part showed marked traces of the longitudinal banding due to their earlier foliation.

The Trough seems to be a line of special stress between the two ice-streams, the one made up of the tributaries from the North Col and eastern slopes of Pt. 22,090 of Changtse, and the other the main mass of the glacier to the east, and its formation would appear to be due to the compression of the smaller western ice streams by this main eastern mass, especially in the narrow constriction between Pt. 22,090 and the opposite side (western spur of Khartaphu), through which the whole of the glacier must pass. A glance at the map will show clearly the bottle-neck character of this outlet and how at the critical point an extra tributary from the western slopes of Khartaphu adds its quota of ice to the already constricted mass. And it is just here that the conditions of stress above referred to are met with, and the Trough develops. The constriction appears to set up forces of compression and shear that along the line of englacial moraine from the north-east shoulder reaches its maximum, the upper layers of ice being fused and the lower layers only retaining their necessary viscosity or rigidity on account of their solid morainic content.

It may be objected that if, as postulated above, the ice is definitely fusing under compression, it should appear in the liquid state along the line of greatest stress, and perhaps even be present as a stream of water
Inciipient ice pinnacles formed from the walls of the "trough".

End of tributary to East Rongbuk glacier near camp II, showing seasonal bedding split into pinnacles by movement and melting.
"NIEVES PENITENTES" FORMED FROM AN ICE-CLIFF, EAST RONGBUK GLACIER

PINNACLES OF THE "TROUGH"

PINNACLES OF "TROUGH," SHOWING STEEPEST SIDES TO THE SOUTH
flowing down the Trough. Actually the latter showed no signs of earlier or later water erosion, nor was there present in it a stream of water until late May, and then only in its lower part after its junction with the moraine from Pt. 22,090 above referred to. On theoretical grounds, even if partial melting took place with the development of interstitial or interfoliate water along the line of greatest compression, such water as was liberated at the surface would tend to be quickly evaporated under the prevailing conditions of aridity and low pressure. Whilst in the light of Mr. C. S. Wright's researches on Antarctic ice and his conception of ice structure on the line of the quantum theory (to use his own words, Geogr. Joum., March 1925, p. 212), "the development of heat by pressure should not bring about melting, but the resulting energy cause an increase in the number of mobile ('vapour') molecules which merely have a tendency to diffuse to points (within each individual crystal) less favoured in this respect." And it must be noted that "this diffusion does not require a free surface for its operation." In this view, presumably, the line of the Trough, owing to the operation of exceptional outside forces, should have an increased mobility; and it may be this which helps to produce a drag and cause the system of faultings above its commencement, already referred to.

The Trough therefore, in my opinion, would appear to be a permanent feature of the East Rongbuk Glacier; permanent, that is to say, under the present conditions of glaciation. That the explanation given above is probably not the whole story of its origin I am quite prepared to admit, for though my conclusions as to its formation were formed on the spot, they were made somewhat hurriedly in the little time available. And, moreover, it was more and more impressed upon one during one's short stay that the unique glacial conditions of this region are deserving of years of special study to understand all fully.

Ice-Pinnacles.

Connected with the phenomenon of the Trough was the perhaps even more striking one of the gigantic ice-pinnacles, that have lent themselves so well to photography. They had their best and largest development in the lower part of the Trough, though their birth was traceable to the walls of the upper portion. As these walls became weathered and melted back differentially during the bodily progress of the Trough down the glacier, buttresses and spurs make their appearance, and tend eventually, in proportion as the processes of ablation and thaw increase in the lower reaches of the glacier, to become detached and stand in isolated masses. And an important factor, which promotes undoubtedly their tapering and spired form, is that of the high-altitude sun of these latitudes, which during the middle hours of the summer day can shine down on them from a position within comparatively few degrees of the zenith and so produce a nearly equal melting effect on every side. The slight inclination of the
sun to the southward does however, produce a marked steepness on all their southern sides.

In a similar way in different parts of the glaciers was to be seen the incipience of pinnacles from smaller ice cliffs than those of the Trough, the process being frequently started by morainic material (like small glacier tables) protecting the ice column beneath them from the steep rays of the sun, and when the protecting cap fell off, the pinnacle assuming a sharp conical or pyramidal form. A similar genetic process can be ascribed to the pinnacles of the main Rongbuk Glacier and others, the principal necessary conditions being a preliminary splitting of the glacier surface into cliffs of whatever size and steep solar rays to act upon them. The phenomenon of "nieves penitentes," first described from the Andes, is undoubtedly equivalent in its genesis to that of these enormously larger pinnacles, conditions of latitude, etc., being similar; in fact, typical examples of normal nieves penitentes were to be seen on the Mount Everest glaciers.

Earth Pillars.

Fine examples of these were to be seen on the steep slopes of old moraine above the end of the main Rongbuk Glacier. Some of them were 20 feet or more in height, although the capping stones, essential especially to the earlier stages of their growth, were in most cases missing. Their continuance in spite of this loss is only another indication of the diminished precipitation of the region.

Polygonal Surface Markings.

I was particularly interested to come across examples of these frost-jointing forms, since they are confined almost entirely to the circumpolar regions. I cannot here go into the question of the mechanism of their formation; suffice it to say that Mr. J. S. Huxley and the writer, from investigations in Spitsbergen, have already described the rôle of frost action as being the primary genetic process (Geogr. Journ., March 1924). A climate that is fairly dry and has for a portion of the year at least a temperature alternating repeatedly on either side of the freezing-point, is productive of the best results. Hence the rare occurrence of the phenomenon in low latitudes, unless other factors such as altitude come in.

The present examples were seen at an altitude of about 17,000 feet on an old upper moraine terrace of the main Rongbuk Glacier on its eastern side. They were mostly stone polygons about 4 feet across, with a network of secondary fissure polygons within the former. The stone borders were composed chiefly of slatey material, as is so frequently the case in the Arctic, and on excavation these were found to be quite superficial, extending down only 2 or 3 inches into the mud. No "tjaele," or frozen soil, could be found beneath. In order to get some indication of the forces acting, and if possible to confirm our earlier views as to these, I displaced some of the stones from the borders, but in
the short interval of observation—about a month—no movement was
discernible, though much drying out of the ground had taken place.
Besides these compound "stone-fissure polygons," there were to be seen
systems of the simple fissure-polygons, quite small in size, and with
appearances of relatively recent formation, giving the impression in this
case of desiccation rather than repeated frost action.

**Former Extent of Regional Glaciation.**

With such clear evidence in the Mount Everest region of a once greater
extent of the glaciers, let us endeavour now to form a picture of the state
of affairs when the maximum phase of the Glacial Cycle was operative.
Reference has been made to the former much greater bulk of the Rongbuk
Glacier. But I think without doubt the most amazing cases we saw of
the once enormously greater expansion of these Tibetan glaciers was
west of the Lamna La, where huge moraines bordered the valleys de-
bouching from the south on to the plains. And perhaps the wide valley,
in whose upper reaches lies the Kyebrek Glacier, was most impressive
of all in this respect. Here immense morainic ramparts towered nearly
200 feet on either side above the wide alluvial valley, and extended to
the Tingri plain, a distance of 15 miles or more from the present snout
of the Kyebrek Glacier. Hence in all probability the present site of
Tingri was once engulfed by ice. Now throughout our march from
Sikkim by way of the valleys of the Chiblung Chu and Phung Chu was
plain evidence in the systems of terraces along the hillsides of former
extensive flooding of these valleys. In as far as I was able to investigate,
these terraces in scarcely any cases indicated fluviatile action alone, and
there can be no doubt that such accumulations of material as are to be
found on the Lingga Plain, and in particular the typical boulder clay in
the gap west of Kyishong, represent fluvio-glacial, if not direct glacial,
deposits. In the hilly tract of country around the Ruli La, and particu-
larly in a valley north of Dra, were to be seen terraces and cliffs of boulder
clay, in places tunnelled out in a curious manner and presumably con-
noting the work of glacial streams during the local wane of the ice.

It is unnecessary to multiply these illustrations. Nevertheless, I
must refer to the case of a peculiar find on the Phusi La at the head of
the Rongshar Valley. Here Beetham brought to me a rounded clay
pebble, split on one side and exposing the whorls of an ammonite cast:
a specimen of indubitable Jurassic origin. As already mentioned, the
rocks found *in situ* in this district are entirely of the pre-Jurassic Meta-
morphic Series, and there are but three possible explanations of the
occurrence of this Jurassic specimen on the Phusi La. Either it repre-
sents an ice-borne erratic that has been carried something like 20 miles
from the nearest Jurassic outcrops to the north and dropped on this pass
of 17,000 feet under conditions which must imply an ice flood sufficient
to overflow the lowest cols of the present divide of the main range and
reverse the northward flow of many existing glaciers; or it was carried to the top of the pass and deposited there by some wily Tibetan in order to involve the inevitable foreign traveller in scientific difficulties and wranglings; or alternatively it was dropped accidentally (we must hope so in view of the last statement!) by Dr. Heron, when he crossed this same pass in 1921 with Col. Howard Bury, on the assumption that an unfortunate hole in his pocket let slip such a specimen that must have been collected many miles away in the Jurassic zone! Personally, I incline towards the first alternative, though the difficulties resulting in its adoption are very considerable. I could find no unequivocal evidence of other erratic material on the Phusi La, and the rounded character of the surface features may have been caused by sub-aerial action other than glacial.

Now if we consider, in the light of such morainic evidence as remains, what the effect on the country of the maximum phase of the Glacial Cycle must have meant, we must conclude that the ice completely blocked most of the valleys, and in fact that in many instances the ice-streams were linked up on this north side of the main chain. Whether during the maximum stage the ice-floods were ever sufficient to form a more or less continuous sheet, of the nature of what in the Arctic has been called "Highland Ice," is questionable; more morainic or other evidence must be found, apart from the solitary Phusi La specimen, before such a thesis can be confidently maintained. But if such were the case, the range lying to the north and forming the southern boundary of the Tsangpo watershed would have at any rate its passes overrun by the ice; and under similar conditions one can only assume that considerable portions of the Tibetan Plateau to the north would be in like manner engulfed.

It is difficult to resist this inference when one considers such a highly elevated tract as Southern Tibet subjected to the frigid conditions known to have obtained elsewhere. At the same time the question must be borne in mind whether during the European Glacial Epoch the then precipitation was sufficient to accumulate the amount of ice suggested above—at any rate, in the plains of Central and Southern Tibet. Dr. Hedin has assured me that he found no certain evidence from glacial deposits of an ice-sheet as far south as the Trans-Himalayan Ranges. But for all that one must conceive of a great accumulation of ice in between the latter and the Great Himalayan Range, during the Glacial Epoch, for there is no reason to suppose that the general trend of monsoonic precipitation was much different then than now; and if, as the stratigraphical and structural evidence earlier cited rather suggests, the Great Range has become progressively elevated since Pleistocene times, due, possibly, to relief of its ice-load or some other isostatic adjustment, its once less formidable barrier may have allowed of even greater precipitation on the northern side than at the present time.
EARTH PILLARS ON OLD MORaine OF Rongbuk Glacier

Sand-blasted granite in wind-gap near base camp
STONE-POLYGONS WITH SECONDARY FISSURE-POLYGONS WITHIN THEM: OLD MORaine TERRACE OF RONGBuk GLACIER

CREScentic SAND-DUNE IN PLAIN AT JUNCTION OF CHIBLUNG CHU WITH PHUNG CHU

LOOKing DOWN JUNCTION PLANE OF UPPER CALcaREOUS SERIES (LIGHT) AND BIOTITE GNEISS (DARK) FROM 28,000 FEET ON MOUNT EVEREST
GLACIERS OF MOUNT EVEREST: DISCUSSION

But whether regionally this were the case or not, the local maximum ice-mass in the Tingri and Kyebarak districts would have to be sufficient not merely to raise the present surface of the Kyebarak Glacier by over 1000 feet—an inconceivable amount taking into account the subsequent erosion of its bed—but by such an amount more as would give a trend to the mass southward over the Phusi La and other passes, in order to carry the Jurassic specimen, and any other similar material, to its position on the former from the nearest parent outcrops to the north. Such an ice mass surging over the lower cols of the Great Range, would send its glaciers far down on the southern side of it, much below the limits reached by the present representatives.

Although I could find no unmistakable evidence in the Rongshar of the presence of a glacier below 14,000 feet, I feel decidedly that more extensive search than I was able to make, pent up as one was in what is most probably a profoundly “overdeepened” gorge, would reveal at least as low moraines as those found by Prof. Garwood in the Lachen Valley of Sikkim at 8790 feet: certainly at Trintang (12,000 feet) in the Rongshar could be seen a shelf on the valley side very suggestive of earlier glacier formation. And in regard to the suggestion that the Tibetan Plateau may at one time have had such an accumulation of ice that it overflowed the present waterparting, Dr. Blanford long ago showed that there was distinct evidence of such having occurred at the head of the Lachen Valley, a dictum in which Prof. Garwood was inclined to concur (‘Round Kangchenjunga,’ p. 299). Although without further extensive work it may perhaps be premature to suppose, as the writer has sometimes ventured, that the great transverse gorges of the Himalayan axis may have been largely due to the work of glaciers descending from a Tibetan ice-cap, or from a Highland ice mass as postulated above, yet we may consider that when the upper Arun basin was occupied with the ice it must have held during the Glacial Epoch, this mass and its concomitant moraines must have had a considerable effect, especially during its wane, upon the natural trend of the drainage, and very conceivably been the determining factor in the astounding course taken by the River Arun at Yô (Rî) and in its upper reaches of the Yaru Chu. All these fascinating problems can only be solved if and when political restrictions cease, and further work can be done amongst the innermost recesses of this important and little-known portion of the Great Himalayan Chain.

The map published with this paper is based upon Major Wheeler’s survey of the immediate environs of Mt. Everest, with the geological formations roughly indicated. The other districts mentioned in the paper can be found on Dr. Heron’s map (G.J., June 1922) and the significance of the observations followed therefrom to some extent.

Before the paper the President said: This afternoon we are to have the result of Mr. Odell’s observations upon the physiography of Mount Everest.
Sketch Map of MOUNT EVEREST from surveys of the Expeditions of 1921 and 1924.

With GEOLOGY added by N.E. Odell.

Scale of Miles

Published by the Royal Geographical Society
Sketch Map of MOUNT EVEREST from surveys of the Expeditions of 1921 and 1924.

With GEOLOGY added by N.E. Odell.

Scale of Miles

Heights in feet
Camp ▲
Pass ▼

Published by the Royal Geographical Society
ROCKS AND GLACIERS OF MOUNT EVEREST

made in the course of the last Mount Everest Expedition. I have not had
the advantage of discussing with Mr. Odell the chief points of his paper, and
I do not know, therefore, what particular points he is to deal with, but I
understand that amongst the surface features of Mount Everest there are two
which certainly require explanation in that one would not expect them to be
there at all. The first is the immense mass of ice on the North Col with
nothing, apparently, to feed it; and the other is the trough in the East Rongbuk
Glacier. I will ask Mr. Odell to tell us what he has to say on the subject.

Mr. Odell then read the paper printed above, and a discussion followed.

Mr. R. D. OLDHAM: I do not think I have anything to say, except that I
have listened to the lecturer's paper with very great interest, and considerable
admiration for the amount of work he was able to do, in very difficult circum-
stances. From personal experience of what working at high altitudes means,
I can fully appreciate these difficulties, although my own limit never exceeded
20,000 feet.

Mr. A. F. R. WOLLASTON: I am not really competent to make any com-
ments on Mr. Odell's paper, but I cannot agree with him with regard to his
explanation of the mass of ice on the top of the North Col. I think that the
amount of precipitation during the monsoon period is quite sufficient to account
for it. If it were a decaying relic of a very large former mass of ice, I think it
would take up another form; it would probably be flattening out. However,
that is a matter of opinion. Moreover, I am not convinced by Mr. Odell's
account of the causation of the trough in the East Rongbuk Glacier. It seems
to me that a great deal more evidence is required before his explanation can
be accepted as sufficient.

Mr. F. G. BINNEY: I am afraid it is rather a red herring to compare the
trough in the Rongbuk Glacier with the so-called "ice-canals" which we found
in North-East Land last summer. We were sledging on an ice-cap, not more
than 2000 feet high, in a region where the ice was disturbed by no nunataks,
while Odell made his observations on a normal glacier. But as these appear
to be two unique glacial phenomena, I shall briefly describe the main points
of the "canals," though I can offer no explanation for their existence.

We were sledging from the east coast to the west coast, and approximately
in the centre of the island we traversed a region pitted with long lines of
"canals" (or channels) in the ice. These channels ran from north to south,
as far as the eye could see. They ranged in breadth between 30 feet and
100 feet. In most places they were bridged over or choked up with hard
congealed snow, which was concave and sagged below either lip of the channel.
Invariably we found small crevasses on either side of the central mass of
snow, not more than 3 feet across and usually bridged with soft snow.

In some places the whole channel was exposed, there being no snow bridge
or chock. We looked down into a chasm some 40 feet deep. Its base was
a mass of congealed snow in a chaotic condition. Nordenskiold describes
how during his journey the party camped in these channels. It would have
been quite impossible to pitch a tent on any of the open parts of the channels
which we observed. We were two days in this region, in thick fog and snow.

The PRESIDENT: It only remains for me to express to Mr. Odell the
gratitude of this audience for the trouble which he has taken in putting before
us the results of his observations. He has given possible explanations of the
mass of ice on the North Col, and also the trough in the East Rongbuk Glacier.
I was a little disappointed that he was unable to offer any explanation of
RACIAL MIGRATIONS IN THE BALKANS

those amazing sheets of fluted snow which are such an outstanding feature of the mountains in that part of the world. I have often gazed upon these vast walls of fluted snow with feelings of astonished admiration, and I had always understood that the most likely explanation was the falling of matter from higher ground, but I understand that Mr. Odell says that that is not a possible explanation, though he is unable to offer any explanation in its place.

Mr. N. E. Odell: I think in the majority of instances there does not seem to be sufficient evidence of, say, a cornice above to give the effect of a scouring of the face in that way by avalanches. The flutings seemed to be present where such conditions were non-existent.

The President: At any rate, Mr. Odell has given us an enormous amount of information this afternoon, and a great deal of material which will certainly be of profound interest to geologists. I should like to express to him our deep gratitude for the trouble which he has taken, and the thanks of this audience I accord to him on your behalf.

RACIAL MIGRATIONS IN THE BALKANS DURING THE YEARS 1912-1924

A. A. Pallis

DURING the last twelve years the Balkan Peninsula and in particular the provinces which changed hands as the result of the Balkan Wars of 1912-1913 and the Great War of 1914-1918, namely, Macedonia and Thrace, have witnessed mass-movements of whole populations on a scale which can hardly be paralleled, unless we go back to the period of great racial migrations which coincided with the break-up of the Roman Empire.

These mass-movements were, partly, the result of direct warlike operations, such as the flight of the Moslem population of Eastern Thrace during the advance of the Bulgarian army up to the lines of Chataldja in October 1912, the flight of the Bulgarian population of Central Macedonia before the advancing Greek army in June 1913, and the flight of the Greek population of Western Asia Minor and Eastern Thrace following on the Turkish victory in Anatolia in August 1922; partly the result of political reprisals and persecutions, such as the expulsion of the Greek population of Western Thrace in 1913, the expulsion of the Greeks of the Thracian and the Anatolian littoral by the Young Turkish Government in 1914, and the wholesale deportations of the Greeks and Armenians of Eastern Thrace, the Marmara, and Pontus to the interior of Anatolia in 1915-1916; partly the consequence of voluntary emigration following on the transfer of territories, such as the emigration of the Greeks of Monastir, Gevgeli, and Strumitsa and of the Moslems of the Macedonian districts ceded to the Balkan Allies in 1913-1914; partly the result of formal agreements for the exchange of populations between