Geological Results of the Mount Everest Expedition, 1921

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badly lame, and that if we stayed where we were discovery would be certain. The only course left us was to "cast" part of the loads and to trust to luck. We left behind all we could dispense with, redistributed the loads, and stumbled on into the night. The rest was a nightmare of confusion, of tumble and scramble, of bruised feet, and of falling about for want of sleep, until we got down into the Wadi Araba just as the moon rose behind us over the hills which we had been clambering down for the last five hours." After getting across the Araba depression (here 12 miles wide) they experienced the same difficulty in the hills opposite; the guide came to the end of his knowledge and was sent back. But eventually they struck a well-marked track which was supposed to be the Ma'an–Kuntilla route; then they camped after "completing over twenty hours on end, with only two halts." The next morning "a search with the glasses revealed three white objects like buildings to the north; we bore down on them, and found them to be the police post of Kuntilla."

Shakespear passed on to Suez, Port Said, and Europe a contented man, having achieved his ambition, and having added his jot (no small one) to the sum-total of human knowledge.

GEOLOGICAL RESULTS OF THE MOUNT EVEREST EXPEDITION, 1921

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Read at the Afternoon Meeting of the Society, 10 *April* 1922. *Map follows p.* 480.

THE area geologically examined consists of over 8000 square miles, included within a rectangle some 120 miles from east to west and 70 miles from north to south. This corresponds with the Tibetan portion of the drainage area of the Arun river, a complicated system of valleys which unite to form the Arun before it breaks through the main Himalayan range in the impressive gorge below Kharta. The headwaters of the Rongshar Chu and the Bhutia Kosi (Pö Chu) above Nyenyam were also examined.

The southern watershed is the line of great snowy peaks running from the Khombu pass south-eastwards through Everest and Makalu to the Arun, and to the east of the Arun is the continuation of the range which divides Sikkim from Tibet; a range which lies considerably to the north of the great Kangchenjunga group of peaks.

The northern watershed is the extension of what has been termed the Ladak or northern range of the Central Himalaya; there this is hardly a definite range but rather a broad belt of high and much-dissected country, with a few peaks of over 20,000 feet distributed without linear arrangement. To the north of this watershed short tributaries drain to the Brahmaputra (Tsangpo).

I am greatly indebted to the promoters of the Expedition for the privilege of accompanying it, and in particular to Colonel C. K. Howard-Bury, D.S.O., the leader, for much assistance and practical interest in my work, which is virtually a continuation, to the westward, of Sir Henry Hayden's pioneer investigations during the Tibet Expedition of 1903–4. With the exception of Sir Henry Hayden no geologist had visited this part of Tibet.

The geological mapping was done on a scale of ¼ inch to 1 mile, on skeleton maps furnished by the topographical surveyors as their plane-tabling proceeded. My very cordial thanks are due to Major H. T. Morshead, R.E., D.S.O., in charge of the Survey of India detachment, for many such facilities given and for valuable information, accompanied by specimens, from localities which I could not visit. Over a oonsiderable portion of the area, however, my work had to proceed in advance of the surveys; geological boundaries in such cases were drawn on the maps subsequently from memory, supplemented by sketch-maps and notes. It was not considered advisable to arouse the suspicions of the Tibetans by too close and prolonged examination of any particular area, and the general conditions of the Expedition's movements were unfavourable to detailed work, so I endeavoured to traverse as large an area of Tibet as possible, and to lay down on the map with fair accuracy the boundaries of the different formations where they were accessible. A considerable amount of interpolation was however, necessary, and my work must be considered as a reconnaissance and nothing more.

If I have the good fortune to accompany the second expedition I hope to examine more carefully the crystalline area in the neighbourhood of Mount Everest, with the assistance of Major Wheeler's map, constructed from photographic surveys on a scale of 1 inch to 1 mile, and to cast some light on such problems as the origin and constitution of the banded biotite gneiss and its relationships with the metamorphosed sedimentaries. The quarter-inch map was on too small a scale to be of use in the mapping of a crystalline complex.

Geologically the area is divided into two divisions: Tibetan and sedimentary to the north, and Himalayan and crystalline to the south. This distinction is clearly displayed in the topography resulting from the underlying geological structure, for to the north we have the somewhat tame rounded and lumpy mountain ranges of Tibet, with their broad and flat-bottomed valleys, contrasting with the higher, steeper, and more rugged Himalayas on the south.

The Expedition found nothing of economic interest. Stones showing the green staining of copper compounds were now and again seen on moraines, but beyond that I saw no signs of mineralization. A few clear fragments of pink tourmaline and garnet were picked up by the coolies, but none were sufficiently free from flaws to be worth cutting. I panned the gravels in several places for gold, but without getting a colour.

The River Systems.

The two main branches of the Arun river, the Bhong Chu (or Men Chu, as it is called in its upper portion) and the Yaru Chu (Ko Chu) flow from the west and the east respectively, in a general east-and-west direction, uniting near the village of Lashar and then flowing south-westwards and southwards through the main Himalayan range. The Yara Chu rises in the hills to the north of Kampa Dzong and meanders through the broad plain which here lies at the northern foot of the snowy range, until at Sar it meets a high spur of crystalline rocks projecting northwards. This deflects it in a great sweep to the north-east and it finally cuts through the toe of this spur in the Rongme gorge instead of flowing round its end.

The Men Chu rises on the northern slopes of Gosainthan, above the Pekhü Tang, a great plain which contains a basin of enclosed drainage, the Pekhü Tso. On leaving the plain it finds its way along a valley excavated in a syncline of Cretaceous limestones, leaves that and cuts across the intervening Jurassic shales in a fine gorge to another parallel limestone syncline, and after some 16 miles along it is deflected back again to the original syncline by a north-south barrier of pegmatite veins and hard slates. Along this it then flows as the Bhong Chu for between 50 and 60 miles to near its junction with the Yaru. Two of its more important northern tributaries, the Shi Chu and the Lo Chu, also have their courses largely determined by the presence of softer bands of Cretaceous limestones. Parallel to the Bhong Chu and joining the Arun 20 miles below the confluence at Lashar is the Dzakar Chu, which, with its tributaries the Ding Chu and the Neo Chu, drains the mountainous district of Pharuk. In these also the synclinal origin of the valleys is distinct. The main drainage lines are therefore parallel to and dependent on the folding to which the region has been subjected; the general strike of the folds is W.N.W.–E.S.E.

At approximately right angles to the longitudinal drainage system are a number of transverse tributaries. Those from the northern slopes of the Great Himalaya are turbulent glacial torrents, with straighter courses and greater discharge than those from the Ladak range. Of the latter the more important occupy valleys intervening between tracts of high land which owe their prominence to their being composed of hardened and partly metamorphosed shales with clusters of intrusive granite veins. Except for glacial tarns held up by moraine dams, the Arun region is devoid of lakes; at either end, however, are basins of enclosed drainage, that of the Tsometretung to the east, and to the west that containing the Pekhü Tso, the Kharru Ochen Tso, and the Khumen Tso. All these are very shallow and vary greatly in extent according to the season of the year. In the broader valleys are extensive swamps

ENTRANCE TO THE YÖ RI GORGE OF THE ARUN RIVER

Phot. A. F. R. Wollaston.

EXIT OF THE ARUN FROM THE YÖ RI GORGE

and tracts temporarily flooded during the rains, and the so-called lakes are in fact little more.

Changes in drainage lines.

There is little doubt that the Arun has cut back through the Great Himalaya range and has captured a river which possibly flowed east from the vicinity of Gosainthan more or less along the present courses of the Men Chu and the Bhong Chu and then through the Jikkyop gap and over the plain to the south of Kampa Dzong; this river may even, as Hayden (*Mem. Geol. Surv. Ind.*, 36, pt. 2, p. 8) suggests, have flowed northward to join the Tsangpo, perhaps on the line of the Nyang Chu, the river which passes Gyantse and Shigatse. The Dzakar Chu, now also captured by the Arun, probably joined the above conjectural river flowing north-eastwards on a course approximately from the Küyok La, above Lungme, along the present valley of the Arun between Kharkhung and Lashar.

The Arun has two gorges. The lower, in which the river falls 3000 feet in the 18 miles, measured in a straight line, between Kharta and Kyimateng, is fairly straight, with walls rising 5000 feet and more in uninterrupted slopes so steep as to prevent human passage but allowing bushes and trees precarious roothold. The upper gorge is an extraordinary one, and so far I am unable to give an explanation of its origin. Where it enters the gorge the river is flowing through a fairly open valley with immense terraces of boulders and gravel, in the direction of the Küyok La, a low pass over comparatively soft schists. Abruptly the river turns upon itself and then plunges at a right angle into the heart of a high mountain (Yö Ri) of hard gneiss, in a gloomy cañon with almost vertical walls. Through this gorge the river flows south for 3 miles, then swings again and flows west for 4 miles, finally emerging from the gorge on the other side of the Küyok La, into an open valley, which has exactly the same line and character as the original valley. Thus it cuts along two sides of a triangle in hard gneiss, in preference to along the hypotenuse in soft schists. The Rongme gorge on the Yaru Chu is somewhat similar, as the stream now cuts through the end of a northward-trending spur of gneiss and adjacent hard phyllites. It seems probable from the configuration of the country that the Yaru once flowed through the Jikkyop gap 4 miles to the north, the present course of the Chiblung Chu, and has been captured by a tributary from the east.

I was able this year to devote only an occasional day or two to the vicinity of glaciers, but it is hoped that next year, with the advantage of a large-scale map on which glaciers will be shown with particular accuracy, I may be able to carry on glacial observations concurrently with the investigation of the crystalline area, to which they are confined. I am able to add my testimony to that of Hooker, Blanford, Hayden, Garwood, and others, as to the former much greater extension of glaciation. The present glaciers are but puny representatives of their former selves, as shown by the huge moraines which encumber all the northern valleys. Two at least of the main glaciers of Makalu, flowing to the Kama valley, show evidences of recent advance.

The Himalayan Zone.

The Himalayan and crystalline zone is essentially composed of a foliated and banded biotite gneiss, usually garnetiferous, intimately injected with dykes and sills of all sizes of a schorl-muscovite granite or pegmatite. The latter is often present to such an extent that it is the predominant rock. Forming an intermediate zone between the gneiss and the Tibetan sedimentaries is a band of metamorphic rocks, altered representatives of the latter: these are also penetrated by the schorl-granite in great profusion. They appear to lie upon the gneiss, which which is probably intrusive in them; but this point is one which I hope to settle definitely if I accompany the second expedition. Other questions which arise are, to what extent the gneiss represents very highly metamorphosed sedimentaries, and to what extent it is an injection gneiss formed by the intrusion and rolling out of granite veins along the foliation of mica-schists.

Although much the same in mineral constituents, the biotite gneiss varies so greatly in proportion, in structure, and in texture that it is difficult to believe that it all has the same origin. Much of it is undoubtedly derived from granite, as, for example, the porphyritic "augen gneiss" type, and a less common variety, found in large amount near Kharta, showing thin and rather sparse foliæ of biotite with abundant felspar, forms lenticles twisted and contorted. In the Kharta and Dzakar valleys the gneiss resembles that around Darjeeling, in which dark and light bands, biotitic and felspathic respectively, alternate, and form a rock which from a little distance has the appearance of a bedded sedimentary series. As near Darjeeling, the planes of foliation or banding have usually low dips, and this variety is notably garnetiferous. Low down in some of the valleys towards the Nepal frontier, as for instance below Nyenyam and Tazang, and also probably near Kyimatang, large bodies of mica-schist are found, analogous to the schist occurring in the bottom of the Teesta valley near Darjeeling and in other localities found underlying the gneiss of Sikkim.* The latter have been mapped by Bose as the Daling Series; it is however quite uncertain whether the schist near the Nepal frontier is an altered sedimentary series or is a modification of the gneiss.

* Garwood, in Freshfield's 'Round Kangchenjunga,' p. 275; Mallet, *Mem. Geol. Surv. India*, **11**, pt. 1; Bose, *Rec. Geol. Surv. India*, **24**, pt. 1, p. 46; pt. 2, p. 217.

The schorl granite varies in texture from a fine homogeneous granite to a coarse porphyritic pegmatite, sometimes with graphic intergrowths of quartz and felspar. It is the latest in age of the igneous rocks, and occurs practically everywhere in the crystalline area, penetrating both gneiss and metamorphics in veins and sills of all sizes. The sill habit is especially characteristic, concordant with the foliation of the rocks intruded. Intrusion has taken place to such an extent that schorl granite is often seen to be the predominating rock, and not only so, but its toughness and lack of joints and foliation cause it to resist weathering and abrasion in moraines and streams, so that it nearly always is the main constituent of detrital accumulations. It has as accessory minerals quartz, plagioclase, black tourmaline (schorl) and muscovite, garnet, yellow and pink tourmaline, and beryl.

The metamorphics comprise a considerable variety of rocks, all of which, except certain quartzites, are distinctly banded or foliated in layers of differing mineral composition, with directions determined by the original stratification. As I proceeded on tour shortly after the return of the Expedition I have not had an opportunity of examining fully microscopic sections of these rocks. They range from quartzites and micaceous quartzites to mica-schists and tourmaline mica-schists, representing the arenaceous and argillaceous sedimentaries, with crystalline marbles and actinolite, tremolite, and epidote schists from the calcareous rocks.

Graphitic schists have also been noted, but are rare. They are dislocated by profuse intrusion of vein granite, and their planes of foliation lie as a rule at comparatively low angles; this is striking in the field, especially in comparison with the intense crumpling which the same rocks have undergone in the Tibetan Zone. As one ascends any of the headwaters of the Dzakar Chu towards the Mount Everest group, one leaves the twisted and crumpled Jurassic shales and passes downwards in the section, as the general dip is northwards, though actually rising in elevation to the gently rolling limestones underlying them, which flatten out as they become more altered and the snowy range is neared. In the Rongbuk valley, for instance, above the Chöbu monastery, are limestones much fissured and veined with crystalline calcite, underlain by a thick sill of schorl granite and pervaded by innumerable smaller sills and streaks. Some 60 feet of the limestone immediately above the main sill has been converted into amphibole schist, and below the sill is a band of mica-schists thickly streaked and knotted with granite in lit-par-lit injection, to such an extent that the result has a very strong resemblance to the banded variety of the biotite gneiss. In the gorge of the Dzakar Chu between Kal and Tsa is exposed a great thickness of flaggy limestones with clayey partings. At the base of the section there are great masses of schorl granite with amphibole and epidote calc-schists; upwards the former become more definitely sill-like, insetbedded with calc-schists and finely crystalline and mottled limestones. The limestones remain crystalline for a considerable distance above the horizon of the topmost sill, and then pass upwards into black limestones, non-crystalline and calcite veined, finally succeeded by Jurassic shales and quartzites. In the valleys above Raphu and Chödzong alteration takes place independent of granite intrusions, calcite-veined, knotted and brecciated limestones passing downwards into tremolite, actinolite, and epidote schists. In the above described sections the change from sedimentary to metamorphic rock is very clearly seen, taking place gradually in magnificent cliff-faces with no break nor discordance in the stratification; from a short distance away it is indeed often impossible to say whether one is looking at limestone or calc-schist.

Speaking generally, the valleys to the north-west and north of Everest, *i.e.* valleys above about 15,000 feet, are excavated in metamorphic rocks, whereas those to the north-east and east, for the most part below about 15,000 feet, are in gneiss. It was impossible, in the time at my disposal and with a small-scale skeleton map, to attempt to lay down a boundary between metamorphics and gneiss, but it would appear possible that the metamorphics form a gently northward dipping sheet underlain by the gneiss. The gneiss is probably intrusive in the metamorphics, judging from evidences of its age elsewhere in the Himalayas, and it may be possible to ascertain this definitely if I am allowed to accompany the second expedition.

The group of high peaks between the Nangba La and the Rongbuk glacier and the north-western side of Everest itself up to the summit are of metamorphics, with of course much schorl granite, to the resistant power of which, and not the easily eroded metamorphics, is due the eminence of these peaks. When I visited the Kharta and Kama valleys on the east side of Everest before the end of the monsoon, the mountain was too much covered with fresh snow to show any geological structure. The base of Chomo Lönzo in the Kama valley is gneiss, but Col. Howard-Bury states that its upper portion is pale granite.

Amphibolites.

In the neighbourhood of Dak, in the Arun valley, numerous fragments of amphibolites, both foliated and granitoid, were observed, but the parent mass was not found. Their nature is therefore uncertain, but they are probably altered igneous rocks of intermediate or basic composition.

The Tibetan Zone.

The Tibetan Zone consists in the main of a great thickness of intensely folded Jurassic shales, the folds in general striking east and west, and repeated many times in complicated fashion. Pinched up in these, in several very elongated and narrow synclines, are limestones belonging to the Kampa System of Hayden, of Cretaceous and Eocene age. These synclines are closely compressed and overfolded, their axial planes dipping to the north, showing that the compressive force which produced them acted from the north.

Along the southern border of the Tibetan Zone, below the base of the Jurassic shales, is a great thickness of flaggy limestones, in which the fossils have been destroyed and the rocks themselves converted in part into crystalline limestones and calc-schists. The age of these cannot be determined with certainty, but their character and position in the sequence indicate that they are possibly Trias or Permian.

I am much indebted to my colleague, Mr. G. H. Tipper, for identifying for me the small collection of fossils which I made. From a palæontologist's standpoint the country which I covered was very disappointing. The Jurassic shales are almost unfossiliferous, and yielded only a few ammonites, belemnites, and crinoid stems of little interest. The thick limestones bordering the crystalline zone show, near their top, abundant signs of organisms in the form of curved layers of crystalline calcite, which in all probability are the remains of large lamellibranchs or brachiopods, but several days' search in favourable localities failed to discover a single specimen of which one could say anything more definite. This is particularly unfortunate in view of the interest attaching to these rocks and their age.

The Eocene and Cretaceous limestones, the zones of which have been worked out in great detail by Sir Henry Hayden in the magnificent and less disturbed sections of the Kampa ridge, here occur in much compressed synclines, in which fossils have been destroyed or damaged by the shearing which they have undergone, and in which zones are almost impossible to work out owing to faulting and interruption by stretches of alluvium. It is only in the Tsipri ridge that a satisfactory detailed study of the Eocene and Cretaceous rocks can be made, and this I was unable to give time for, as when I passed it I had been separated from the Expedition by floods and had exhausted all my money and nearly all my food. It is, however, unlikely that I could have added anything of value to Sir Henry Hayden's description of these rocks.

The Kampa System.

The Kampa System is developed in two main synclines, the northern of which may be called the Tsipri syncline, from the picturesque and sacred ridge on it, and the southern the Bhong Chu, from the chief river of this area, which has excavated its valley along it; there are besides a number of small synclines. The Eocene beds above the "ferruginous sandstone" of Hayden (*Mem. Geol. Surv. India*, 36, Pt. 2, pp. 44, 48–51) are found only in the northern syncline.

In the exposures between the Yao La and Gutso this is a massive pink and white quartzite, about 100–150 feet thick, weathering into large blocks. In its degree of metamorphism it is a typical Pre-Cambrian quartzite, although the brown shales below it and the blackish grits above are almost unaltered; the latter contain fossil wood, dicotyledonous, and is the highest formation present in the section. The Tsipri ridge gives the only fair sections of the combined Eocene and Tertiary of the Kampa System.

I was unable to examine in detail, but the general section is as below:

Bold scarp: Massive thick-bedded grey limestones, with abundant Alveolina and Operculina, alternating with massive, white, very fine-grained and unfossiliferous limestones and thin-bedded limestones.

Minor scarp: A series of limestone in regular beds of medium thickness; about the middle of this series comes the "ferruginous sandstone."

Undercliff of above: Grey flaggy limestones.

Lower scarp rising from plain: Brown argillaceous limestones, in thin regular beds.

Usually covered, but exposed at east end of ridge: Great thickness of grey unfossiliferous calcareous shales.

East end of ridge: Black and brown splintery shales with large septarian nodules.

North side of Shi Chu Valley: Grey limestone, massive quartzite, the "wall" quartzite.

The upper limestones on the south side of the ridge are corrugated, and as they pass to the northern side dip steeply up to the vertical; further north, on the northern side of the Shi Chu valley, the limestones and quartzite at the base of the syncline are inverted, with the Jurassic shales overlying them and dipping to north at 30° to 80°. The Shekar hill shows a subordinate anticline formed to the north of the main syncline. At the western end the topmost limestones come down to plain-level by a downward pitching of the syncline, and are seen in the short ridge to the west of Temi with undulating dips and a great overfold.

In the Tsipri ridge the ferruginous sandstone is not so highly indurated in the Yeo La sections; it has abundant spherical concretions of iron oxide and is in certain layers finely conglomeratic, the little pebbles, of the size of buckshot, consisting of transparent quartz, quartzite of various colours, and white chert.

At the western end of the northern syncline, where it emerges from the alluvium of the Pekhu plain, the Cretaceous limestones in their upper portion have numerous intercalated thin bands of sandstone and are themselves distinctly arenaceous, indicating, with the occurrence of fossil wood in the Eocene grits above the ferruginous sandstone, the prevalence of shallower water conditions than obtain as one passes to the east.

The structure is that of a recumbent isocline, of which both limbs dip north at 20° to 40°, affected however by minor rollings and corrugations, and the northern margin is considerably altered by metamorphic agencies connected with the granite intrusions of the Northern Range.

Locally the prominent sandstone quartzite band which is found elsewhere in the shales a little distance below the base of the limestones is wanting. This I call the "wall" quartzite. Here there is a passage into the Jurassic shales through shaly limestones. Just below these passage beds, at Menkhap Me and on the Lungchen La, fragments of ammonites of Upper Jurassic type, but not determinable with certainty, were found.

East of Gutse and Menkhap Me a broad alluvium-filled river valley and a southward-trending spur of semi-metamorphic rocks and granite veins (the Burtra ridge) cut off this syncline, but there is little doubt that it is structurally continuous with that of Tsipri. This has been described above. It also is overfolded by pressure from the north.

To the east of Shekar the outcrop of the syncline narrows, through the beds becoming more vertical, and as it swings to the north-east in the valley of the Lo Chu it flattens out again to a very recumbent isocline.

A day's search in the Cretaceous beds round Shekar failed to yield a fossil; the beds appear to have been sheared to some extent, and are shattered and veined with calcite but not rendered crystalline. In the Lo Chu valley the shaly partings between the limestones are silvery from the production of sericite mica.

The Bhong Chu syncline is also overfolded, but not to quite the same extent as the last. Like it, it extends to an unknown distance through the Pekhu plain to the westward. Where first encountered, where the Men Chu flows along a valley excavated in it, a wide plateau of undulating Jurassic shales lies to its south, on which is a shallow saucer-like syncline, containing the "wall" quartzite and a trifling thickness of limestone above it. At the edge of this plateau the shales and the "wall" quartzite roll steeply over into the Men Chu valley.

On the northern bank of the stream is a fine scarp of regularly bedded limestone, in places crowded with small lamellibranchs (unidentifiable) and what appear to be casts of brachiopods in crystalline calcite. To the north of this a double fault is well seen, bringing this limestone against the "wall" quartzite and the Jurassic shales, these dipping vertically where they meet.

Between Nelung and Tinkri, where the Bhong Chu again returns into and excavates a valley along the syncline, both limbs dip northward at about 60°. From Tingri eastwards to where it disappears near Tsonga, its southern limb is fairly regular and the "wall" quartzite stands up conspicuously along the valley, dipping at angles of 45° to 80°. Its boldness and continuity along this valley led me to give to this distinctive bed the field name which I have used here. It is about 120 feet thick; next above it is a thin but massive limestone, and then 300–400 feet of shales, passing into the slabby limestones which form the bulk of the visible section.

The northern edge is not so regular; usually it is overfolded, but in places the dip is high but normal, and south of Shekar runs a strike fault, cutting out the "wall" quartzite. South of the Tsipri ridge the two synclines approach closely, with an intervening anticline of Jurassic shales separating them. All along the Bhong Chu valley exposures of the Cretaceous limestones are much disconnected by detrital deposits, and usually occur as isolated hills of bizarre form in which the beds are seen to be intensely crumpled and sheared, and fossils are represented by streaks of calcite. At Kyishong, near where it disappears, the syncline widens out owing to a subsidiary anticline rising up along its centre.

The group of synclines to the south, in the Pharuk district, display great irregularities and complexity of structure, so much so that I found it impossible to map them in detail on a $\frac{1}{4}$-inch scale, and have had to show them in a general and diagrammatic way. That which forms the valley of the Neo Chu and passes eastwards to near Aya is very elongated and narrow; the strata in it stand vertically or lie slightly overfolded in the usual direction, with the "wall" quartzite standing up on either side of the valley. Midway along its length a strike fault repeats it, bringing in a wedge of Jurassic shales between. At its western end it is continued by another similar syncline, not quite in line with it but parallel and a short distance to one side. In the 2 miles south of this, between Namda and Tashidzom, the "wall" quartzite and the basal beds of the Cretaceous limestones are repeated again and again by sharp folds and faults of small throw. Needless to say they are veined with calcite and in places brecciated. South of this again, from Tashidzom to Kuyul, besides the major double syncline shown on the map, small sections of the Cretaceous limestones are pinched up and faulted into the Jurassic shales. In the double syncline there is no inversion, the northern lobe being shallow, saucer-like and fairly symmetrical, while in the southern the beds are undulating and almost horizontal.

The only remaining outcrop of Cretaceous rocks lies far to the north-east, a shallow syncline similar to the last, with the quartzite dipping gently inwards round the periphery and the centre occupied by horizontal and undulating sericitic limestones.

The Jurassic shales.

The most striking features, in fact the only striking features, of the Jurassic beds are the extent and the monotony of their outcrops. They consist for the most part of dark brown and black shales and argillaceous sandstones, with subordinate quartzites, representing the purer type of sandstone, and limestones which are usually darker and more argillaceous than those of the overlying Cretaceous System.

In the tract of country between the crystalline zone and the Northern Range of the Central Himalaya, the Jurassic strata are thrown into great folds and corrugated in the most fantastic fashion, and even where the general dip approaches horizontality the beds roll about irregularly.

In such highly compressed country faulting, especially thrust-faulting, must be very prevalent, but where strata are so uniform in appearance it is extremely difficult to detect. The general strike of these folds is that of the "grain" of the country, *i.e.* in an east-west or E.S.E.–W.N.W. direction, but they are subject to far more irregularities than in the more persistent synclines of the Kampa System limestones.

In the Northern Range, and also where they pass downwards into the thick limestones along the boundary of the crystallines, the shales dip less variably and at lower angles. A certain amount of injection by granite veins has taken place in the Northern Range, along with a widespread regional induration of the rocks, attaining however only a low degree of metamorphism. The intermediate belt, where the Cretaceous and Eocene limestones have been compressed into overfolded synclines and the Jurassic shales have been so intensely folded, has been a region of weakness between two more resistant blocks. The alteration of the rocks in the Northern Range extends considerably further outwards from the areas of granite intrusion than in the opposite section of the Great Himalaya, but is of less degree. Pebbles of garnetiferous mica-schist and hornblende schist (of the "feather amphibolite type") were found in gravels below the Mön La, but the parent rock was not found *in situ*, nor were such highly metamorphosed types met with elsewhere.

Igneous Rocks in the Tibetan Zone.

The intrusive granite of the Northern Range is very similar in appearance to the schorl granite of the Himalayas, but is uniformly fine-grained instead of showing the great variation in texture of the latter rock. Like it, it is a white rock and is very tough and resistant to weathering. Mineralogically it differs from the schorl granite in that it contains biotite (with muscovite as well), instead of schorl.

Near Nelung, Khakyu, and between Namda and Aya, small dykes of dark rock were seen, in the last case strung out along a line running east and west, appearing at intervals over a length of 2½ miles. The dykes individually run only 100 feet, less or more, and are up to 3 feet wide. The rock is too thoroughly decomposed for determination, but is probably basic. Judging from the crushing and dislocation which the dykes have undergone, they are probably antecedent in age to the folding of the rocks.

For the most part the shales have been hardened and have acquired the beginning of slaty structure, being knotted and breaking into prisms, or have developed in them a certain amount of secondary sericite mica and aluminous silicates such as staurolite, and have in certain cases become phyllites. Often they have a baked appearance, being whitish or red, contrasting with the black or rusty brown tints of the unaltered shales. The quartzites show no more alteration than they do amongst the unaltered strata, but then in this area the usual Jurassic sandstone quartzite, fairly free from impurities, is just as hard and vitreous as any typical Pre-Cambrian quartzite.

Permo-Trias Limestones.

Between the crystalline and the sedimentary zones is the outcrop of a thick series of limestones, of which 2000 or 3000 feet are exposed in a very uniform assemblage of rather thin beds of 1 to 3 feet in thickness, with shaly partings. The overlying shales, of which the major portion has been shown by Hayden to be Jurassic, pass down without any visible discordance into the limestones. As has been stated, the limestones as a whole are considerably altered, all fossils having been destroyed and now appearing as streaks of crystalline calcite. More than this, they have been extensively invaded by granite veins, converted into crystalline limestones and calc-schists, and involved in the crystalline complex in such fashion that to lay down a true boundary on the map is impossible. The line which I have drawn between limestones and crystallines is arbitrary, and represents generally the upper and outer limit of granite intrusions: to the south of this line there is much of the limestone in the form of calc-schists, but intimately associated with the schorl granite. The lowest portions of the limestones are thus obliterated and their relation with the biotite gneiss is obscure, but it is probable that the latter is intrusive in them. The limestones were probably continuous right along the southern margin of the Jurassic exposures, but from point to point the zone of metamorphism and granite veining has encroached on them to a varying extent, in some places affecting them throughout and transgressing upwards as far as the Jurassic shales, and in others leaving a great thickness unaltered, so that their outcrop has now the irregular breadth shown upon the map. Their general dip is northward at low angles; at Yalep on the Pö Chu and at Kal are anticlinal flexures, and south of Raphu and Hlelung dips undulate somewhat. The bifurcation of the outcrop north of Tulung is, so far as I was able to ascertain, due to the limestones emerging again to the north of the main exposures along an anticlinal axis. The structure is, however, doubtful, and may be due to faulting. My examination of this portion of the area was much hindered by repeated snowfalls and heavy mist.

The age of these rocks is very doubtful, but may be put down provisionally as Permo-Trias. Sir Henry Hayden (*Mem. Geol. Surv. Ind.*, 36, pt. 2, p. 21) has described, under the name of the Dothak Series, an assemblage of limestones and other sedimentary rocks between the Chumbi valley and Bhutan, which in his opinion may include part or all of the Trias and possibly one or more of the Palæozoic systems.

He also suggests that Triassic rocks occur along the northern slopes of the Lhonak range between Tibet and Sikkim (*Loc. cit.*, pp. 23 and 24), and fossils typical of the Productus Shales (Upper Permian) are known to have been collected from near the Kongra La, the pass which crosses the Lhonak range south of Kampa Dzong. The situation of these exposures with regard to the crystalline zone is very similar to that of the limestones in the present area.

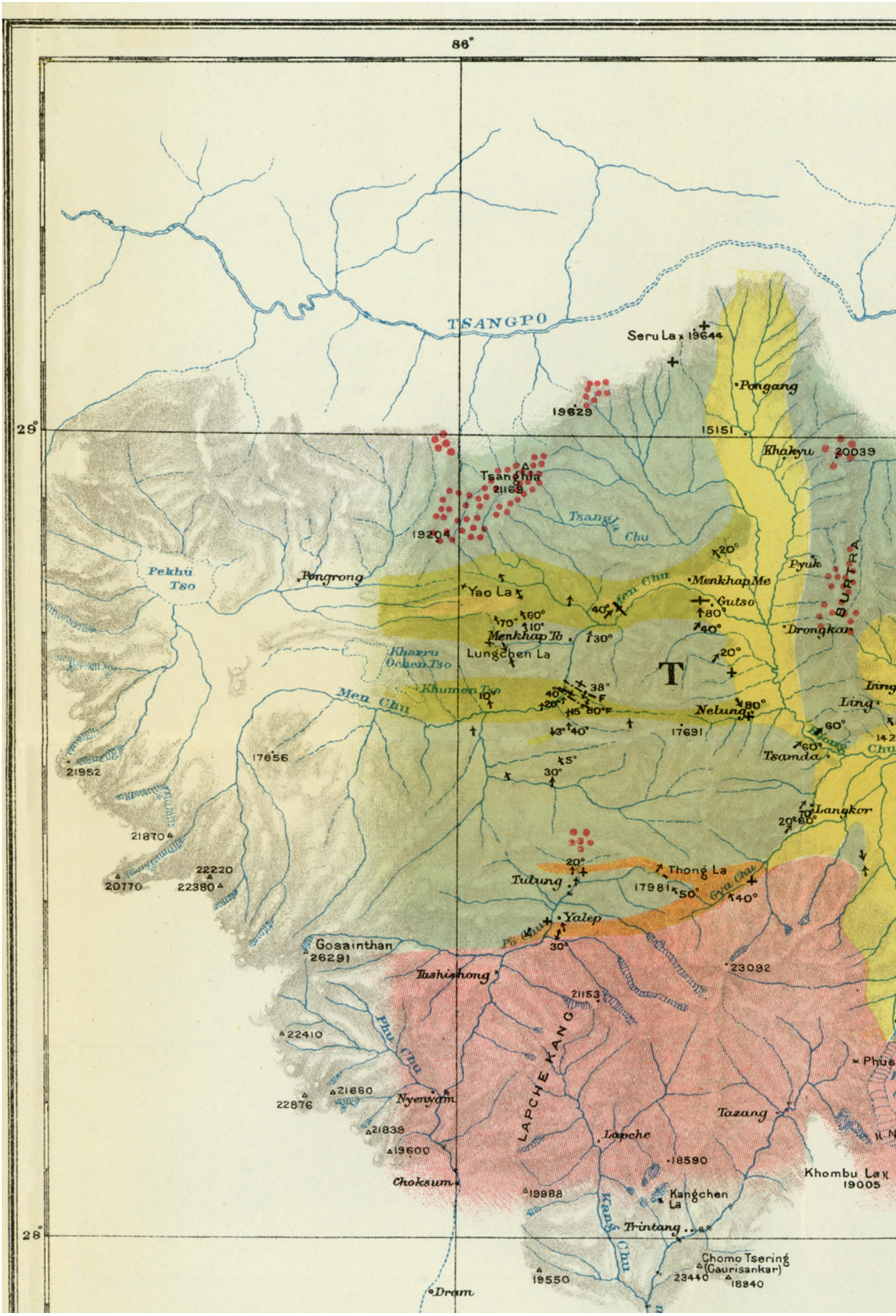
Direct evidence of their age, though not very definite, is given by two sections in the ridges to east and west of Hlelung. At the base of the great series of shales which overlie the limestone, just as they pass downwards into the latter, is a thin ferruginous bed crowded with Spirifer and Productus, not however specifically determinable. These would indicate that the top of the limestones is about Upper Permian in age, if the section is a straightforward one, which there is no reason to doubt. The bulk of the limestones would then represent the Permian of the European scale, with perhaps a portion of the Carboniferous. Judging from field relationships and lithological characters, I had in my own mind considered these limestones as approximately equivalent to the Kioto Limestone of the Zangskar range in Spiti (Lower Jurassic and Upper Trias), which in that country underlies the Spiti shales (Upper Jurassic), but the fossil evidence puts them much lower in the geological scale, and indicates that the Trias is represented by the lower portion of the great succession of shales; it is unfortunate that the absence of recognizable fossils from the limestones themselves leaves the question so indefinite.

Before the paper the PRESIDENT said: The paper this afternoon is one by Dr. Heron, of the Geological Survey of India. He accompanied the Mount Everest Expedition last year on the reconnaissance of the mountain, and has given us the result of that reconnaissance from the geological point of view. He is very energetic, and managed to cover a great deal of country in the region of Mount Everest. Though I do not believe he actually got to the top of the mountain, he did, however, what is from a geological point of view much more interesting—he explored all the region north of Mount Everest towards the Brahmaputra, and also to the east of it. Dr. Heron, unfortunately for us, is not able to be present as he is still out in India. He was hoping to rejoin the Mount Everest Expedition this year also, but I am not sure that he has been able to do so. We are, however, fortunate in having with us Mr. Fox, who also belongs to the Geological Survey of India, and has worked for the Survey in the Himalayas.

Mr. C. S. FOX, of the Geological Survey of India, gave an account of the above paper by Dr. Heron, and added:

The remarkable parallelism between the trough of the Tsangpo and the axis of the main Himalayan range has always been taken to indicate a common origin for both, that is, crust squeeze or pressure at right angles to these features. The same forces would account for the closely corrugated and crumpled sedimentary beds, and for the great double synclinal sag of the Cretaceous and Tertiary strata. It is, however, difficult to explain the tectonics concerning the metamorphism of the sedimentary rocks at the junction of the Tibetan and Himalayan zones.

There are certain peculiarities in the valleys of the Men Chu, Bhong Chu, and Dzakar Chu which require comment. These streams occupy synclinals or structural troughs of Cretaceous strata for part of their courses. Such structural courses are as a rule uncommon. Most streams in mountainous country occupy valleys carved along anticlinal folds. It is therefore thought that these above streams began their courses along anticlinal folds, but owing



86°
29°
28°
TSANGPO
Seru La 19644
Pongang
19629
15151
Khakyu
20039
Tsangthla
21169
Tsangla Chu
19204
Pekhü Tso
Pongrong
Yao La
Men Chu
MenkhapMe
Gutso
Pyuk
BURTRA
Drongkar
Menkhap To
Lungchen La
Kharru Ochen Tso
Khumen Tso
Men Chu
T
Nelung
17691
Ling
Tsamda
17656
21952
Langkor
21870
20770
22220
22380
Tulung
Thong La
17981
Gya Chu
Yalep
Po Chu
Gosainthan 26291
Tashishong
23092
21153
22410
Phu Chu
LAPCHE KANG
Phus
21680
22876
Nyenyam
Tazang
21839
19600
Lapche
18590
Khombu La 19005
Choksum
19988
Kangchen La
Kang Chu
Trintang
Chomo Tsering (Gaurisankar)
19550
23440
18940
Dram

87°
Tolung 18160
Mok Kyong 18160
TSANGPO
Seru La 19644
Pongang
Chi Chu
15151
Khakyu
20039
21263
Maphu La 17844
Chu
20°
Mön La 16323
Pangbo Chu
20230
Men Chu
Menkhap Me
Pyuk
BURTRA
Gutso
Yolcho
Pangbo
Gompa Phu
Lo Chu
Drongkar
Kongtsa
Nagoling
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B
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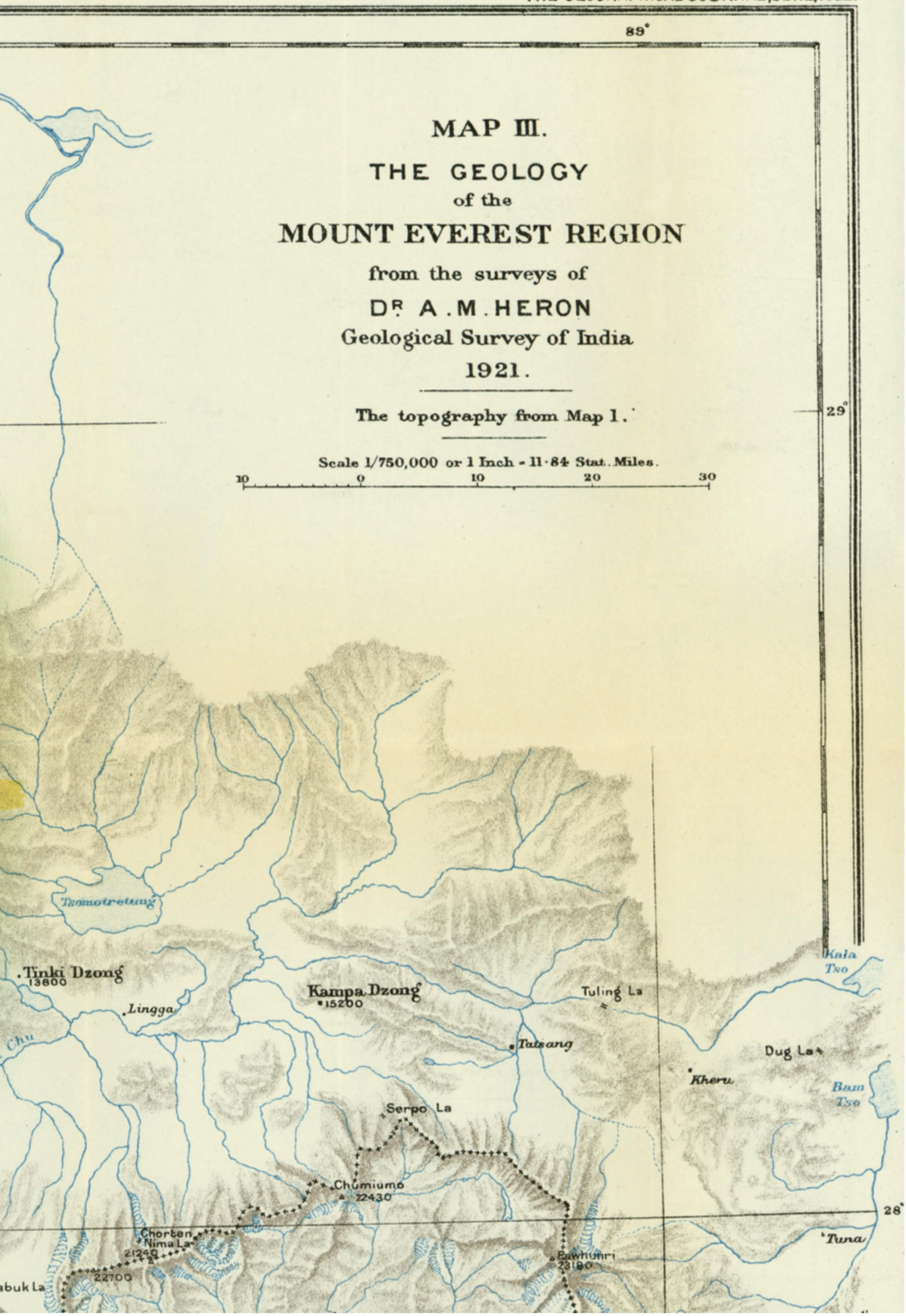
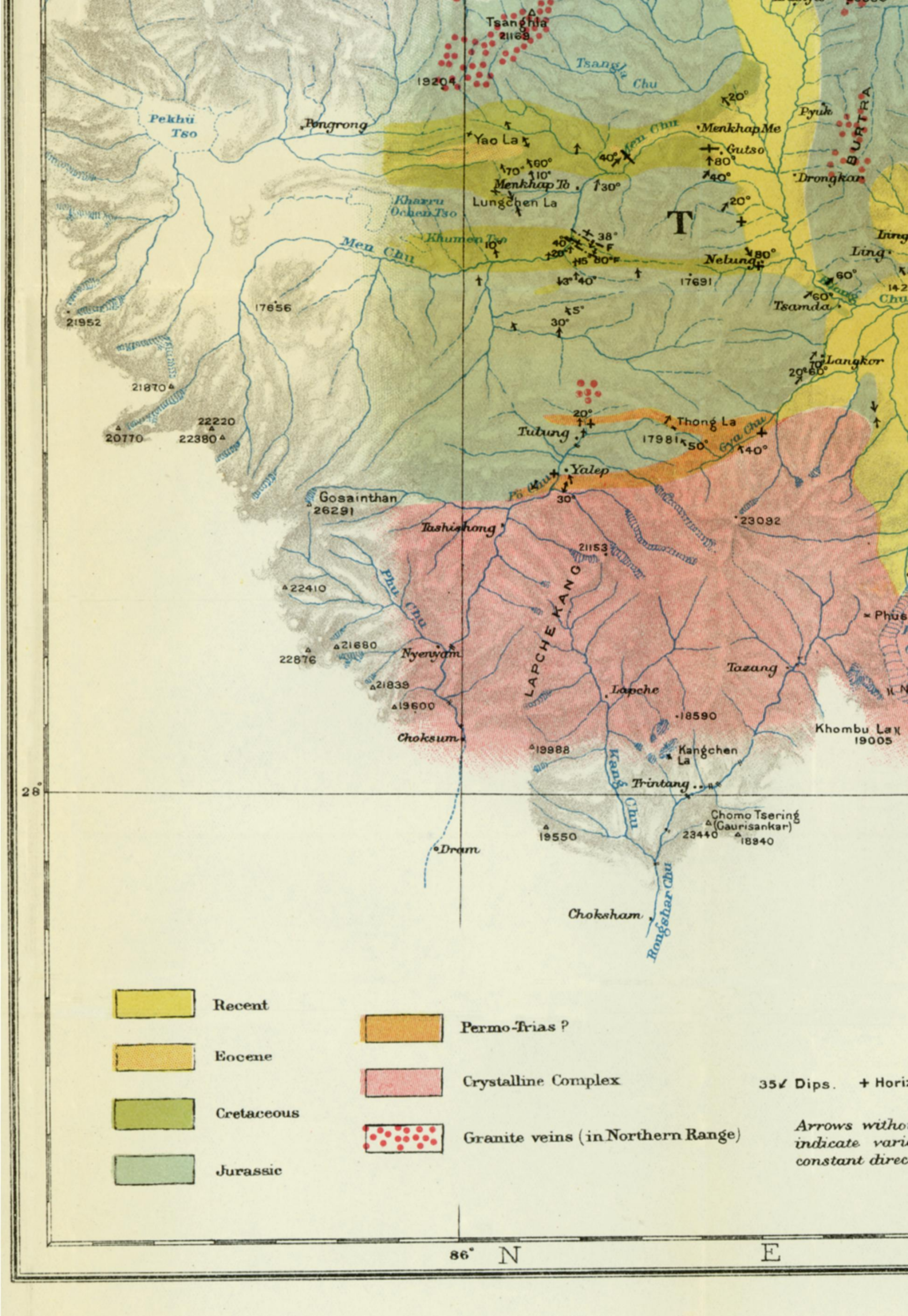
TSIPRI
Shi Chu
Lingshar
Temi
Ling
Shekar Dzong 14619
Nelung
17691
14245
Tsamda
Chasho
Kyishong
Tingri Dzong
Tsakor
Pangla
Ramchen
Bhong Chu
Langkor
18711
Lamar La 18575
Neo Chu
Ruli La
Thong La
17981
Gya Chu
Namda
Tashidzom
Ji La
Mendo
Ding Chu
23092
P
H
A
R
U
K
Kai
Tsa
Kang Gya
Kuyok La
Kharkhu
Rope bridge
Lamna La
Chöbuk
Dzakar Chu
Zambu
Chödzong
Rebu
Lumeh
Yo Ri
Kyetrak
Hlalung
Dak
Gorge
Doya La
Phuse La
Kyetrak Glacier
Rongbuk
Chongphu Chu
K
H
Lang Chu
Tazang
Lapche
Nangba La
Rongbuk Glacier
23080
Khartichangri 23420
Teng
18590
Gyachungkang 25990
Kharta Chu
Khombu La 19005
Cho Uyo 26867
Khartaphu 23800
Kharta
Kangchen La
Langma La
Samchung La
Trintang
Kangshung Gl
Shao La
Valley of Lakes
MT EVEREST 29002
Kama Chu
Chog La
Chomo Tsering (Gaurisankar)
23440
18840
Chomo Lonzo 25413
Sakeding
Bhong Chu


88°
Raga Tsangpo
Mok Kyong 18160
Lhatse Dzong
TSANGPO
Sakya Trom Chu
18850
Mangaphu Chu
16599 Ngogpa La
18269
Garon
21263
Maphu La 17844
Sakya
Puchung Chu
Drimo La
Puchung
Lo Chu
20°
10°
21864
Hlako Kangri 21266
10°
15°
Lolo
E
T
Nyope
ekar-Dzong
5°
Chasko
40°
Kyishong
Ramchen
Pangla
Bhong Chu
Chumbab
Chundu
Jikkyop
Ruli La
Ji La
Shiling
5°
Chablung Chu
5°
Rongme
Mendo
40°
Lashar
Tsomotretung
Gyangkar Nangpa
40°
40°
R
U
K
Kai
50°
45°
Tsa
Kang Gya
Sangkar Ri 20402
80°
Tinki La 16926
Tinki Dzong 13800
Chushar
70°
Kuyok La
Kharkhung
Rope bridge
Lumeh
Yo Ri
Ko Chu
Lingga
Dak
Gorge
20721
Doya La
Yaru Chu
40°
30°
Nyonno Ri 22142
Sar
Chongphu Chu
H
Lang Chu
A
Teng
Ama Drime 21882
Kharta Chu
Kharta
Samchung La
Langma La
Phu Chu
Shao La
Valley of Lakes
Langphu 21508
Chorten Nima La 21240
Chog La
Bhong Chu
Kama Chu
Tashirak
22700
Kang La 18365
Chabuk La
Sakeding
M
10


89°
MAP III.
THE GEOLOGY
of the
MOUNT EVEREST REGION
from the surveys of
Dr. A. M. HERON
Geological Survey of India
1921.
The topography from Map 1.
Scale 1/750,000 or 1 Inch = 11·84 Stat. Miles.
10
0
10
20
30
29°
28°
Tsomotretung
Tinki Dzong
13800
Lingga
Chu
Kampa Dzong
15200
Tuling La
Tatsang
Kala
Tso
Dug La
Kheru
Bam
Tso
Serpo La
Chumiumo
22430
Chorten
Nima La
21240
22700
Pawhunri
23180
Tuna
abuk La


Tsangchia
21168
Tsangla Chu
19204
Pekhü Tso
Pongrong
Yao La
Men Chu
MenkhapMe
Gutso
Pyuk
BURTRA
Drongkar
Menkhap To
Lungchen La
Kharru Ochen Tso
Khumen Tso
T
Men Chu
Nelung
Ling
Tsamda
17691
17656
21952
Langkor
21870
20770
22220
22380
Thong La
Tulung
17981
Gya Chu
Yalep
Po Chu
Gosainthan
26291
Tashishong
23092
21153
LAPCHE KANG
22410
Phu Chu
Phus
21680
22876
Nyenyam
21839
19600
Tazang
Lapche
18590
Khombu La
19005
Choksum
19988
Kangchen La
Kang Chu
Trintang
28°
Chomo Tsering (Gaurisankar)
19550
23440
18940
Dram
Rongshar Chu
Chokzham
Recent
Eocene
Cretaceous
Jurassic
Permo-Trias ?
Crystalline Complex
Granite veins (in Northern Range)
35 Dips.
86°
N
E


T I B E
Maphu La
17844
Mön La
16323
Pyuk
BURTRA
MenkhapMe
Gutso
Drongkar
Yölchö
Pangbo
Pangbo Chu
20233
Gompa Phu
Kongtsa
Naqoling
Lolo
Lingshar
Temi
TSIPRI
Shi Chu
Nelung
Ling
Shekar Dzong
14619
17691
14245
Tsamda
Tingri Dzong
Tsakor
Chasko
Kyishong
Ramchen
Pangla
Bhong Chu
Langkor
18711
Lamar La
18575
Neo Chu
Namda
Ruli La
Ji La
Thong La
17981
Gya Chu
Tashidzom
Ding Chu
Mendo
P H A R U K
Kang Gya
Kuyok La
Kharkhu
Rope bridge
Lumeh
Yo Ri
23092
Lamna La
Chöbuk
Dzakar Chu
Chödzong
Rebu
Kyetrak
Zambu
Hlehung
Dak
Gorge
Doya La
Phuse La
Kyetrak Glacier
Rongbuk
K H A R T A
Chongphu Chu
Lang Chu
Tazang
Lapche
Nangba La
Rongbuk Glacier
23080
Khartichangri
23420
Teng
Kharta Chu
18590
Khombu La
19005
Cho Uyo
26867
Gyachungkang
25990
Khartaphu
23800
Kharta
Samchung La
Langma La
Kangchen La
Kangshung Gl.
Shao La
Trintang
Kang Chu
Valley of Lakes
Chomo Tsering (Gaurisankar)
23440
18940
MT EVEREST
29002
Kama Chu
Chog La
Chomo Lonzo
25413
Saketing
Makalu
27790
Lungdo
Rongshar Chu
Kyimatang
Popti La
Chamlang
24012
S I N G
ARUN R.
35 Dips. + Horizontal. Vertical. F. Fault
Northern Range)
Arrows without numerals indicate variable dip with constant direction.
E P 87° A L
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MT. EVEREST EXPEDITION.

Map III, Geology.