To Dr. B. Asklund

With the Author's compliments.

GEOLOGICAL RESULTS OF THE MOUNT EVEREST RECONNAISSANCE EXPEDITION.

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(With Plates 7 to 13.)

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GEOLOGICAL RESULTS OF THE MOUNT EVEREST RECONNAISSANCE EXPEDITION. BY A. M. HERON, D.SC., F.G.S., *Officiating Superintendent, Geological Survey of India.** (With Plates 7 to 13.)

I.—THE ARUN BASIN, TIBET.

Introduction.

The area geologically examined consists of over 8,000 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 the streams of 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 Nyenam were also examined.

The southern watershed is the line of great snowy peaks running from the Khungphu or Nangba 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 Kanghhenjanga group of peaks. The northern watershed may be the extension of what has been termed the Ladak or Northern range of the Central Himalaya; but here 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. Howard Bury, D.S.O., the leader, for much assistance and practical interest in my work.

* Read before the Indian Science Congress, Madras, 1st. Feb., 1922.

My work is virtually a continuation, to the westward, of Sir Henry Hayden's pioneer investigations during the Tibet Expedition of 1903-04[1]; with the exception of Sir Henry Hayden no geologist had visited this part of Tibet.

My mapping was done on a scale of 4 miles to the inch 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 considerable portion of the area however my work had to proceed in advance of the surveys, geological boundaries in such cases having to be drawn on the maps subsequently from memory, supplemented by sketch maps and notes. The general conditions of the Expedition were indeed unfavourable to detailed work, in consequence of which 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 had had the good fortune to accompany the second Expedition I had hoped 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 the many problems connected with the granites and gneisses and their relationships with the metamorphosed sedimentaries. The quarter-inch map was on too small a scale and was available too late to be of use in the mapping of the crystalline complex.

Geologically the area is divided into two:

(*a*) Tibetan and sedimentary to the north.

(*b*) Himalayan and crystalline to the south. This distinction is clearly displayed in the topography

[1] The Geology of the Provinces of Tsang and Ü in Central Tibet. *Mem. Geol. Surv. Ind.*, XXXVI, pp. 122-201, (1907).

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.

Economically the Expedition met with nothing of interest. On moraines stones showing the green staining of copper compounds were now and again seen, but beyond that I saw no signs of mineralisation. 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.

Physical Features.

River systems.

The two main branches of the Arun river, the Phung 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 southwestwards and southwards through the main Himalayan range. The Yaru 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 for some distance along a valley excavated in a syncline of Cretaceous limestones and then cuts northwards in a fine gorge through intervening Jurassic shales to another parallel limestone syncline; some sixteen miles along this valley it is deflected back again to the original syncline by a N-S ridge-barrier of pegmatite veins and hard shales. Along this syncline it then flows as the Phung Chu for between fifty and sixty 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 the softer bands of Cretaceous limestones.

Parallel to the Phung Chu and joining the Arun twenty 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 tributaries 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 direction of the folds is W. N. W.—E. S. E.

Approximately at 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.

Lakes.

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 Tso Mo Tre Tung to the east and to the west that containing the Pekhü Tso, the Kharru Ochen Tso and the Khömen 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 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 Phung Chu and then through the Jikkyop gap and over the plain to the south of Kampa Dzong: this river may even, as Hayden[1] 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 northeastwards on a course approximately from the Küyok La above Lungme, along the present valley of the Arun between Kharkung and Lashar.

The Arun has two gorges. The lower, in which the river falls 4,000 feet in the 18 miles measured in a straight line between Kharta and Kyimatang, is fairly straight, with walls rising 5,000 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 canyon with almost vertical walls. Through this gorge the river flows south for three miles, then swings again and flows west for four 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 following the hypotenuse in soft schists. The Rongme gorge on the Yaru Chu (Ko Chu of the map) 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 four miles to the north, the present course of the Chiblung Chu, and that it was subsequently captured by a tributary from the east.

[1] *Loc. cit.*, p. 129.

Glaciers.

I was able this year to devote only an occasional day or two to the vicinity of glaciers, but I am able to add my testimony to that of Hooker, Blanford, Hayden, Garwood and others, concerning the former much greater extension of glaciation. The present glaciers are but puny representatives of their former might, as shown by the huge moraines which encumber all the northern valleys. Two at least of the main glaciers of Makalu flowing to the Karma 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, regarded as altered representatives of the latter; these are also penetrated by intrusions of the schorl-granite in great profusion. The metamorphic rocks appear to lie upon the gneiss, which is probably intrusive in them, but this point is one which I was unable to investigate. 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.

Biotite-gneiss.

Although the rock shows but little variation in mineral constituents, it varies so greatly in their proportion, in structure, and in texture, that it is difficult to believe that the whole of the rock is of one 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, in which thin and rather sparse foliae of biotite with abundant felspar form lenticles twisted and contorted in every direction. In the Kharta and Dzakar valleys this resembles a type common around Darjeeling, in which alternate dark and light bands, biotitic and felspathic respectively form a rock which from a little distance has the appearance of a bedded sedimentary series. As is the case 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 Nyenam and Tasam and also probably near Kyimatang, large bodies of mica-schist are found, analogous to the schist occurring in the bottom of the Tista valley near Darjeeling and in other localities said to be found underlying the gneiss of Sikkim.[1]

The latter have been mapped by Bose as the Daling series; it is however uncertain whether the schist near the Nepal frontier belongs to an altered sedimentary series or is a variety of the gneiss.

Schorl-granite.

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 crystallines examined, penetrating both gneiss and metamorphics in veins and sills of all sizes. The habit of the sills is specially characteristic, namely concordance with the foliation of the rocks into which they are intruded.

Intrusion has taken place to such an extent that schorl-granite is often seen to be the predominating rock, and also its toughness and lack of joints and foliation cause it to resist weathering and abrasion in screes, moraines and streams, so that it nearly always is the main constituent of detrital accumulations. In addition to the essential minerals quartz, plagioclase, black tourmaline (schorl) and muscovite, the granite has as accessory minerals garnet, yellow and pink tourmaline, and beryl.

Metamorphic rocks.

The metamorphics comprise a considerable variety of rocks, all of which, except certain massive quartzites, are distinctly banded or foliated

[1] Garwood, in Freshfield's 'Round Kangchenjunga', p. 275; Mallet, *Mem. Geol. Surv. Ind.*, Vol. XI, p. 41 (1874); Bose, *Rec. Geol. Surv. Ind.*, Vol. XXIV, pp. 46, 221 (1891).

in layers of differing mineral composition, the directions of which are determined by the original stratification. They range from quartzites and micaceous quartzites to mica-schists and tourmaline-mica-schists, representing the arenaceous and argillaceous sedimentaries, with crystalline marbles and banded actinolite-, diopside-, and epidote-schists representing the calcareous rocks. Graphitic schists have also been noted, but are rare.

Considering how dislocated are the metamorphics due to intrusion of vein-granite, the comparatively low angles at which their planes of foliation lie as a rule, strike one in the field as surprising, 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 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 Chobu 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 sixty 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 streaked and knotted with granite in *lit-par-lit* injection to such an extent that the product 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-schists; upwards the former becomes more definitely sill-like, interbedded with schists and finely crystalline and mottled limestone. 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, and are finally succeeded by Jurassic shales and quartzites. In the valleys above Raphu and Chödzong alteration takes place independently of granite intrusions, calcite-veined, knotted and brecciated limestones passing downwards into pyroxene-, 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 it may be said that 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 sheet dipping gently northwards and 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 on further investigation.

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 composed of metamorphics, with, of course, much schorl-granite, to the resistant power of which, and not to the easily eroded metamorphics, is due to the eminence of these peaks. When I visited the Kharta and Karma valleys on the east 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 Makalu in the Karma 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. The nature of these amphibolites is therefore uncertain, but they are probably altered igneous rocks of intermediate or basic composition.

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. Pinched up in these folds 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 that direction.

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.

From a palæontologist's standpoint the country which I covered was very disappointing, but I am, nevertheless, much indebted to my colleague, Mr. G. H. Tipper, for identifying for me the small collection of fossils which I made. 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 in several days search in favourable localities I failed to discover a single specimen showing anything more definite.

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 it is almost impossible to work out the zones owing to faulting and interruption by stretches of alluvium. It is only in the Tsipri ridge that a satisfactory and detailed study of the Eocene and Cretaceous rocks can be made; but for this I was unable to spare the time, for when I passed it I had been separated from the Expedition by floods and had exhausted all my money and almost 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 Phung Chu syncline, from the chief river of this area, which has excavated its valley along it; there are besides a number of smaller synclines.

It is in the northern syncline only that the Eocene beds above the 'ferruginous sandstone' of Hayden* are found.

In the exposures between the Yao La and Gutso this 'ferruginous sandstone' is a massive pink and white quartzite, about 100—150 feet thick, weathering into large blocks. In its degree of metamorphism it is like a typical Pre-Cambrian quartzite, although the brown shales below it and the blackish grits above are almost unaltered; the latter contain dicotyledonous fossil wood, and are the highest formation present in the section.

The Tsipri ridge gives the only fair sections of the combined Eocene and Cretaceous of the Kampa System. I was unable to examine this 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.

* *Loc. cit.*, pp. 165, 169-172.

Minor scarp . . .	A series of limestones 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 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 outcrop of the topmost limestones descends to plain-level due to a westward pitch of the syncline; in the short ridge to the west of Temi, they show undulating dips and a great overfold.

In the Tsipri ridge the ferruginous sandstone is not so highly indurated as in the Yao La sections; it contains 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, contain 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; 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 Gutso 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.

The Tsipri syncline 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 have not been rendered crystalline; in the Lo Chu valley the shaly partings between the limestones are silvery from the presence of sericite mica.

The Phung Chu syncline, also, is overfolded, but not to quite the same extent as the Tsipri syncline. It also extends to an unknown distance through the Pekhu plain to the westwards. Where first encountered, in the west, the Men Chu flows along a valley excavated therein; to the south lies a wide plateau of undulating Jurassic shales, 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 the limestone against the 'wall' quartzite and the Jurassic shales, which dip vertically at the junction.

Between Nelung and Tingri, where the Men Chu, now known as the Phung Chu, returns to and again excavates a valley along the syncline, both limbs dip northward at about 60°. From Tingri eastwards to where the syncline disappears near Tsonga, the 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 followed by 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; 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. All along the Phung 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 its eastern end, the syncline widens out, due to the presence of a subsidiary anticline along its centre.

The groups of synclines to the south, in the Pharuk district, display such great irregularities and complexity of structure that I found it impossible to map them in detail on a $\frac{1}{4}$ inch scale and have been compelled to show them in a general and diagrammatic way. The syncline that forms the valley of the Neo Chu and passes eastwards to near Aya, is very elongated and narrow, with the strata disposed vertically or slightly overfolded in the usual direction, and the 'wall' quartzite standing up on either side of the valley. Midway along the syncline a strike fault repeats it, bringing in a wedge of Jurassic shales. At its western end, it is continued by another similar syncline, slightly *en échelon*. In the two miles south of the Neo Chu syncline, 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 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, and is 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.

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 a 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 in cases 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 such faulting is extremely difficult to detect.

The general strike of these folds is that of the 'grain' of the country, *i.e.*, in a E.-W. or E.S.E.-W.N.W. direction, but the folds are subject to far more irregularities than is the case in the more persistent synclines of the Kampa System limestone.

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 accompanied by a widespread regional induration of the rocks, which attain, however, to 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 is the case in the opposite section of the Great Himalaya, but is, as I have said, of less degree. Pebbles of garnetiferous mica-schist and hornblende-schist (of the 'feather amphibolite' type) were found in gravels below the Mon La, but the parent rock was not found *in situ* nor were such highly metamorphosed types met with elsewhere in the Northern Range.

For the most part the shales have become hardened and have acquired the beginning of slaty structure, being knotted and breaking into prisms, or have had developed in them a certain amount of secondary sericitic mica and of aluminous silicates such as staurolite; in certain cases they have 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.

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, and from the Kyi Chu granite described by Hayden, it differs in the absence of hornblende and the scarcity of plagioclase and of sphene, epidote and calcite.

Near Nelung and Khakyu, and between Namda and Aya, small dykes of dark rock were seen, in the last case strung out along a line running E. and W. appearing at intervals over a length of 2½ miles. The dykes individually extend for only a hundred feet, less or more, and are up to 3 feet in width. The rock is too thoroughly decomposed for determination, but is probably of basic composition. Judging from the crushing and dislocation which the dykes have undergone they are probably antecedent in age to the folding of the rocks. Pebbles of an augite-bearing rock, probably of basaltic or andesitic composition, but with felspars too much altered to be determinable, are common in the gravels of the Phung Chu and may be derived from such dykes.

Permo-Trias limestones.

Between the crystalline and the sedimentary zones crops out a thick series of limestones, of which 2000 to 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. Further, 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 upon the map is impossible. The line which I have drawn between limestones and crystallines is an arbitrary one and represents generally the upper and outer limit of granite intrusions; to the south of this line there is much of the limestone in its metamorphosed forms, but intimately associated with the schorl-granite. The lowest portions of the limestones are thus obliterated and their relation to 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 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 Po Chu and at Kal are anticlinal flexures and south of Raphu and Hlelung dips undulate somewhat.

The bifurcation of the outcrop east of Tulung is, as far as I was able to ascertain, due to the limestones emerging again to the north of the main exposure 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[1] 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 Palaeozoic systems.

He also suggests that Triassic rocks occur along the northern slopes of the Lhonak range between Tibet and Sikkim,[2] 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 the belt of Permo-Trias rocks described above.

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 limestones, just as they pass downwards into the latter, is a thin ferruginous bed crowded with *Spirifer* and *Productus*, not, however, specifically determinable. These

[1] *Loc. cit.*, p. 142.
[2] *Loc. cit.*, pp. 144 and 145.

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 recognisable fossils from the limestones themselves leaves the question so indefinite.

II.—THE GEOLOGICAL STRUCTURE OF MOUNT EVEREST.

During the attacks on the mountain by the climbers of the second Expedition, a small collection of rock-specimens was made at heights of from 23,000 to 27,000 feet. I am greatly indebted to those who collected them, at altitudes and under difficulties hitherto unequalled in geological field-work.

These specimens confirm the views arrived at last year, as a result of inspecting the mountain by telescope from the Rongbuk valley from a distance of about ten miles, and by examination of moraine material derived from its northern faces and spurs.

These data show Mount Everest to be a pile of altered sedimentary rock—shales and limestones—converted into banded hornfels, finely foliated calc-silicate schists and crystalline limestones. The hornfels and fine schists are in the field blackish or dark green rocks, conspicuously slabby and with a general low dip to the north, which I believe adversely and even dangerously affected climbing. The crystalline limestones are fine-grained pure white rocks.

A general description of the various types has been given in the paragraph on metamorphic rocks and it may suffice to say here that the actual specimens from 23,000 and 25,000 feet show in microscope sections a very fine-grained aggregate of quartz and a greenish mica, with irregular lenticles and veins of chlorite and epidote and in addition sometimes calcite and sphene.

The mountain, from 21,000 to 27,000 feet, is made up of these black and dark green rocks, with occasional beds of white limestone and veins of quartz and muscovite-granite. From 27,000 to 27,600 feet extends an almost horizontal belt, a sill in fact, of schorl-muscovite-granite, along the whole length of the mountain, which rock presumably, by its superior hardness, gives rise to the prominent shoulder of the mountain north-east of the main peak (shown as 27,390 on Major Wheeler's photographic survey map). Above this again are black schists.

As to the age of the rocks forming Mount Everest, they may perhaps be assumed, for the present, to be Jurassic or Trias.

EXPLANATION OF PLATES.

PLATE 7.—View of Mount Everest from the north.

PLATE 8.—Geological map of the Arun River Area, Tibet: scale 1″=8 miles.

PLATE 9.—Diagrammatic Sections across the Arun river area, Tibet.

PLATE 10.—FIG. 1.—Alluvial gravel terraces and hills of Jurassic shales, Kyishong, Phung Chu valley.

FIG. 2.—Folded Cretaceous limestones, Men Chu above Mento.

PLATE 11.—FIG. 1.—Folded Jurassic shales.

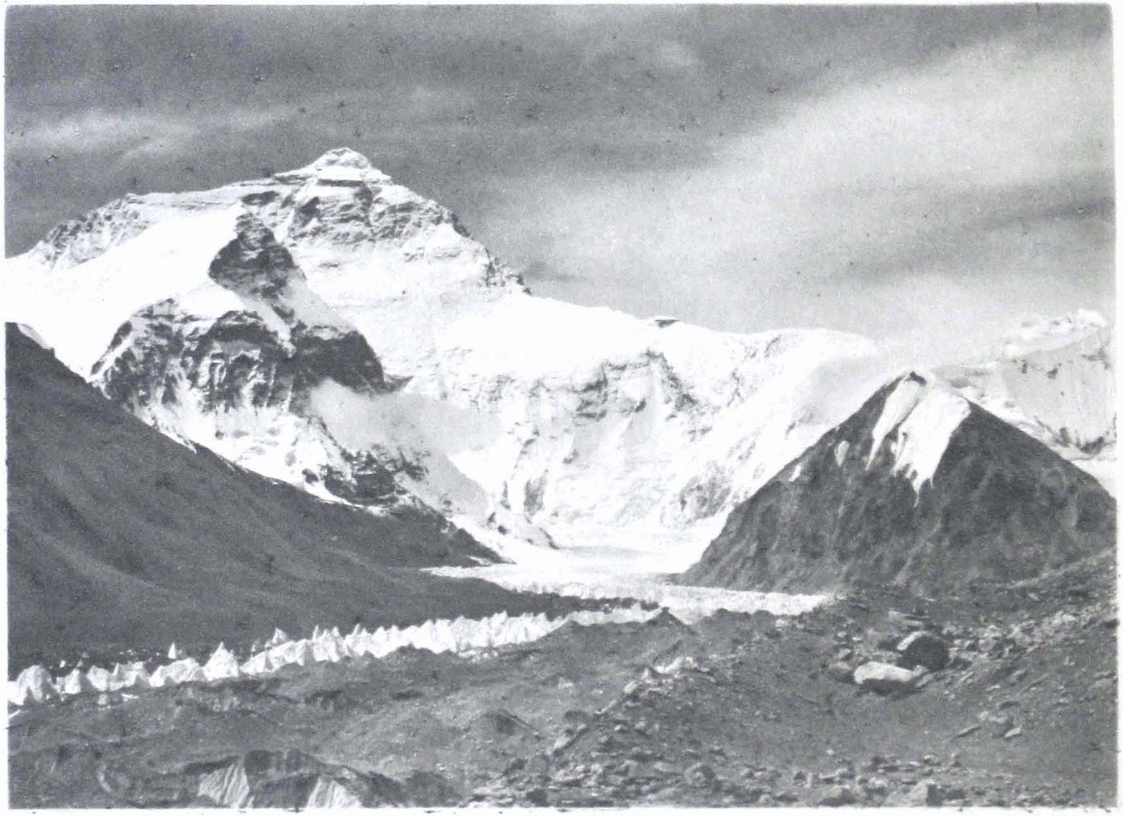
FIG. 2.—General view of Phung Chu valley, from Memo, looking east, Tsipri ridge on right.

PLATE 12.—FIG. 1.—Synclinal hill of Cretaceous limestone, Memo, Phung Chu valley.

FIG. 2.—Eastern end of Tsipri ridge, showing folded Cretaceous limestones.

PLATE 13.—FIG. 1.—Folded Cretaceous limestones, Pelding near Dzakar Chu.

FIG. 2.—Folded Cretaceous limestones, Riphe near Dzakar Chu.

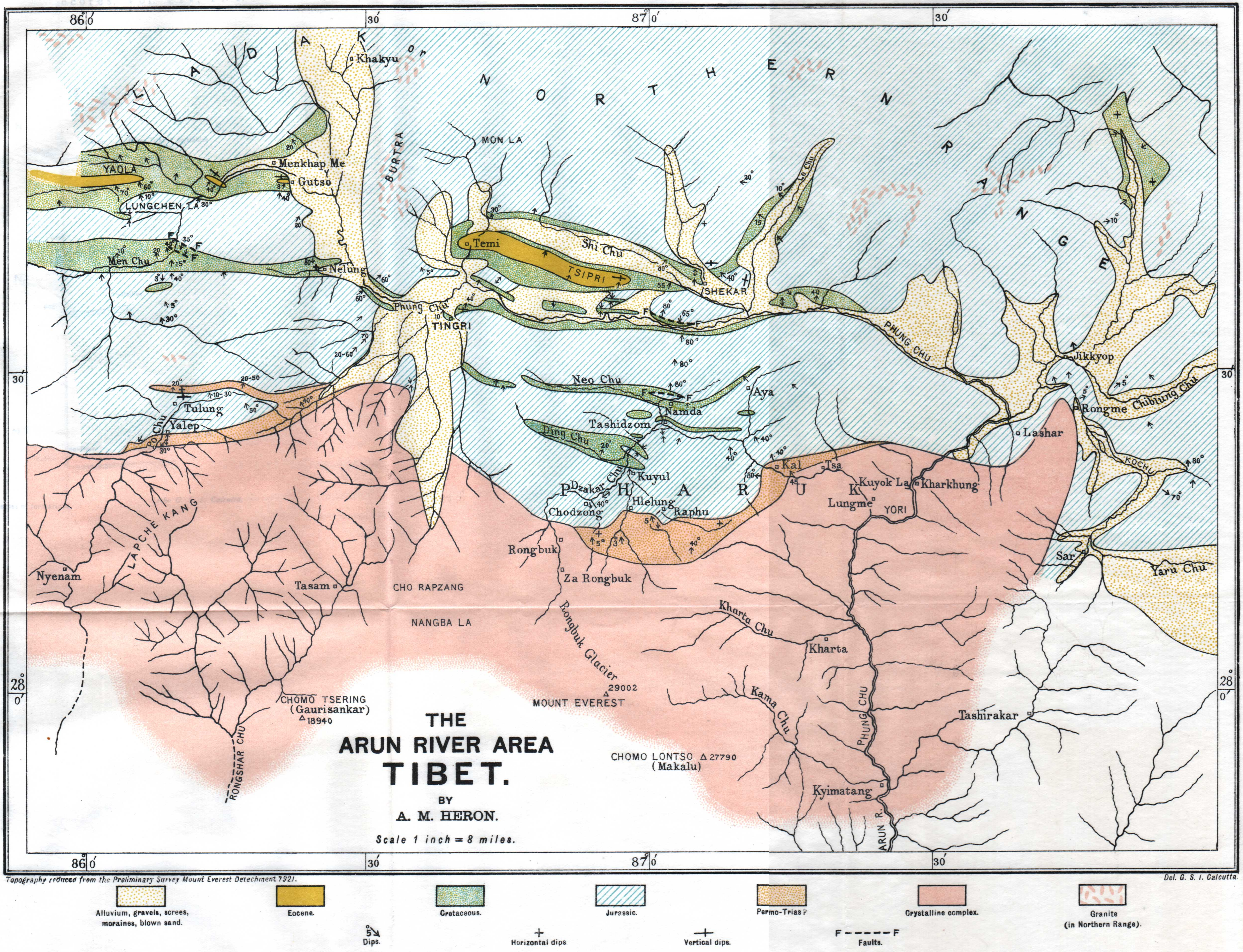


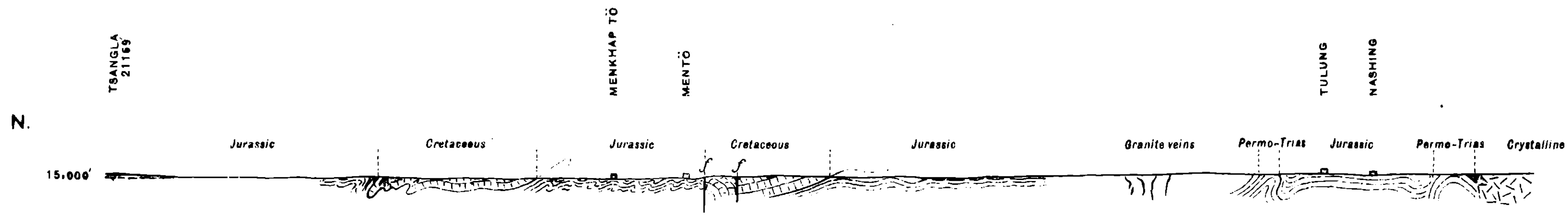
Photographed by A. M. HERON

Photogravure, Survey of India Offices, Calcutta 1922.

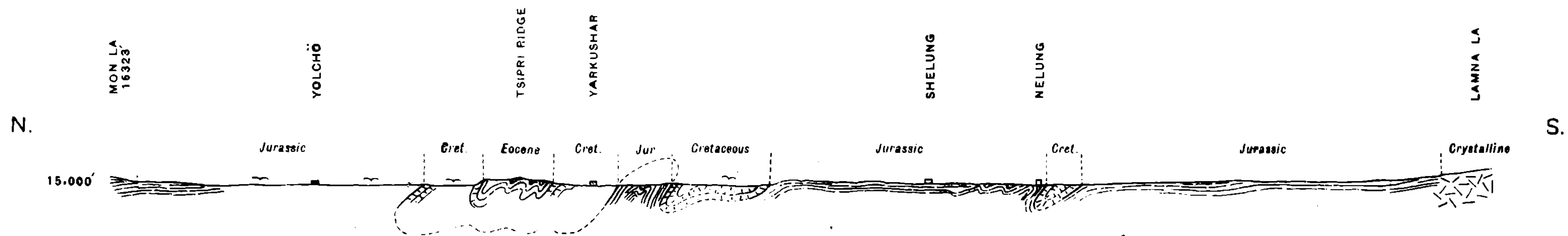
THE NORTHERN FACE OF MOUNT EVEREST.

FROM THE RONGBUK VALLEY, SHOWING NEARLY HORIZONTAL STRATIFICATION OF ALTERED SEDIMENTARIES.

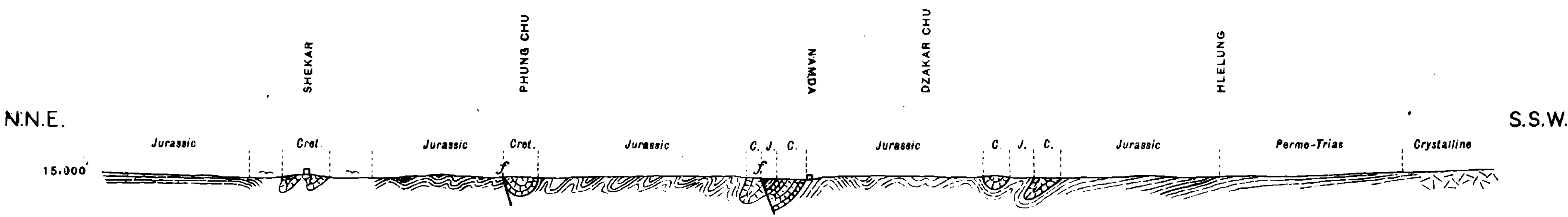

THE
ARUN RIVER AREA
TIBET.
BY
A. M. HERON.
Scale 1 inch = 8 miles.
86°0′
30′
87°0′
30′
28°0′
NORTHERN RANGE
LADAK or
PHARUK
Khakyu
MON LA
BURTRA
Menkhap Me
Gutso
YAOLA
LUNGCHEN LA
Men Chu
Nelung
Temi
Shi Chu
TSIPRI
SHEKAR
Lo Chu
Phung Chu
TINGRI
PHUNG CHU
Jikkyop
Neo Chu
Aya
Namda
Tashidzom
Ding Chu
Tulung
Yalep
Rongme
Chiblung Chu
Lashar
KOCHU
Kal
Tsa
Kuyok La
Kharkhung
Lungme
YORI
Dzakar Chu
Kuyul
Chodzong
Hlelung
Raphu
Rongbuk
Za Rongbuk
Sar
Yaru Chu
LAPCHE KANG
Nyenam
Tasam
CHO RAPZANG
NANGBA LA
Rongbuk Glacier
Kharta Chu
Kharta
Kama Chu
29002
MOUNT EVEREST
CHOMO TSERING
(Gaurisankar)
18940
RONGSHAR CHU
CHOMO LONTSO 27790
(Makalu)
PHUNG CHU
Kyimatang
ARUN R.
Tashirakar
Topography reduced from the Preliminary Survey Mount Everest Detachment 1921.
Del. G. S. I. Calcutta.
Alluvium, gravels, screes, moraines, blown sand.
Eocene.
Cretaceous.
Jurassic.
Permo-Trias?
Crystalline complex.
Granite (in Northern Range).
Dips.
Horizontal dips
Vertical dips.
F-----F Faults.



DIAGRAMMATIC SECTION THROUGH TSANGLA, MENTO AND TULUNG, ALONG LONG. 86° 8′.



DIAGRAMMATIC SECTION FROM THE MON LA TO THE LAMNA LA, ALONG LONG. 86° 42′.



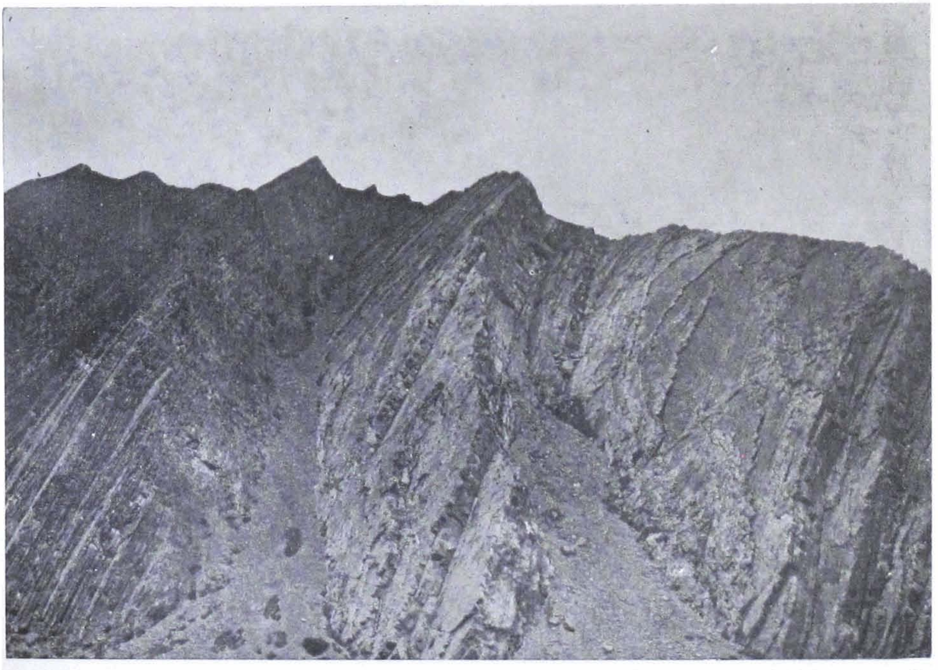
DIAGRAMMATIC SECTION THROUGH SHEKAR, NAMDA AND HLELUNG.

Litho G. S. I. Calcutta.

Thicknesses of formations shown have no exact significance.

Scale of sections 4 miles to 1 inch.

FIG. 1. ALLUVIAL GRAVEL TERRACES AND HILLS OF JURASSIC SHALES, KYISHONG, PHUNG CHU VALLEY.



A. M. Heron, Photos. *G. S. I. Calcutta.*

FIG. 2. FOLDED CRETACEOUS LIMESTONES, MEN CHU, ABOVE MEN TO.

Records, Vol. LIV, Pl. 11.

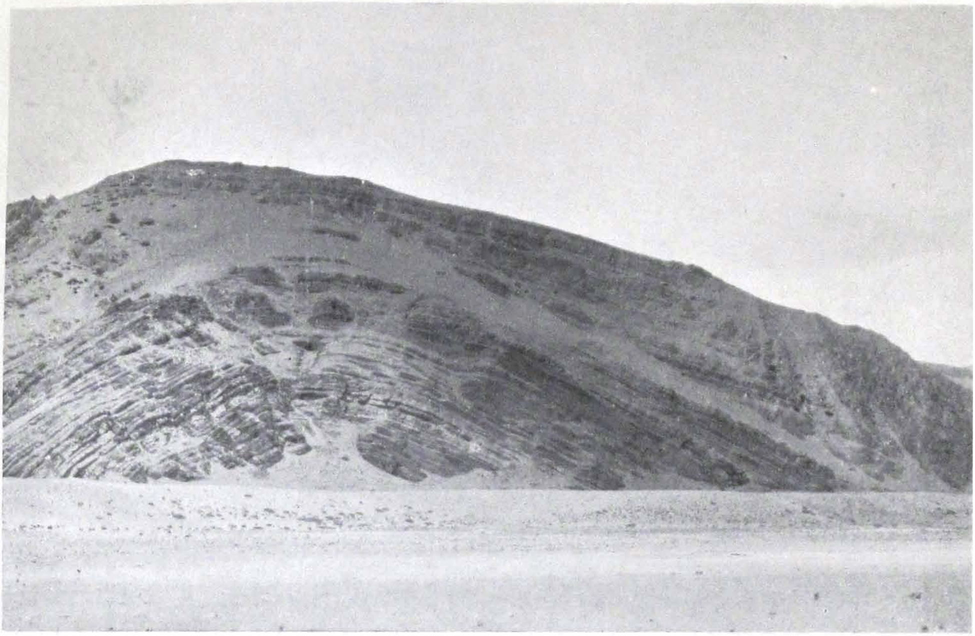


FIG. 1. FOLDED JURASSIC SHALES, NEAR MEN TO.

A. M. Heron, Photos. *G. S. I. Calcutta.*

FIG. 2. GENERAL VIEW OF PHUNG CHU VALLEY, FROM MEMO LOOKING EAST, TSIPRI RIDGE ON LEFT.

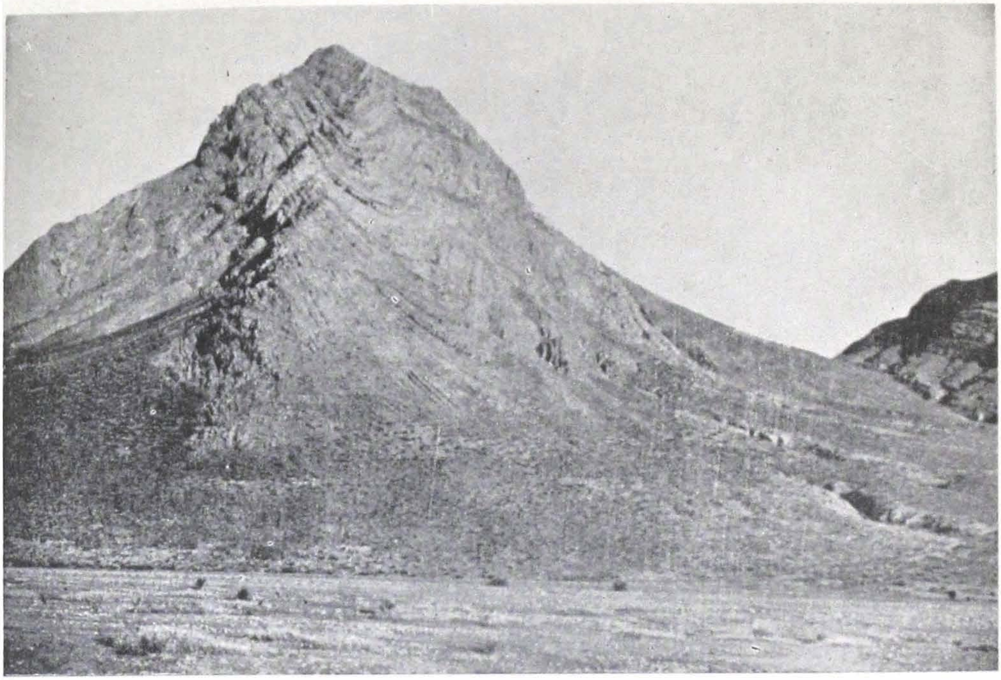
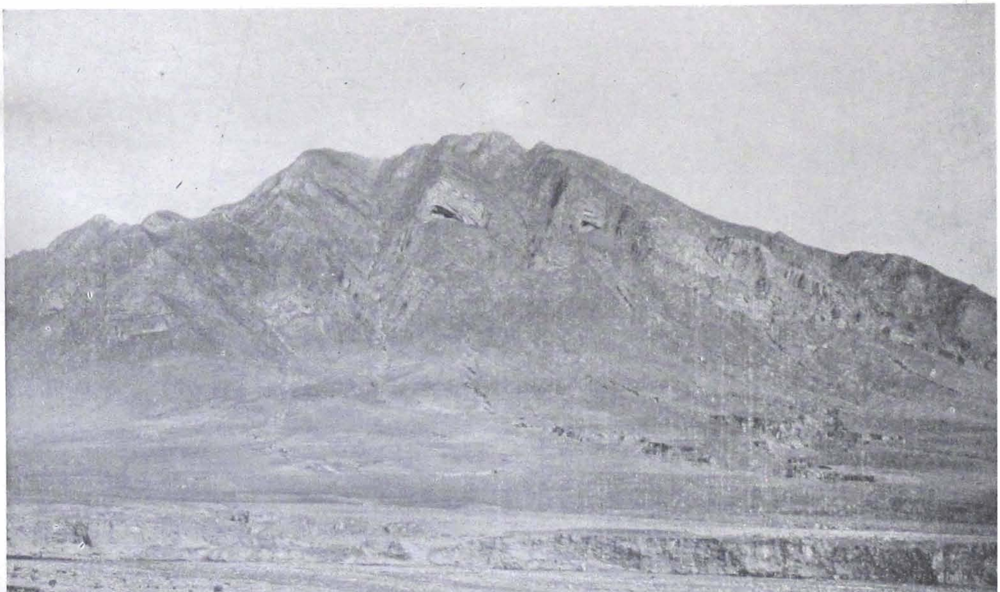


FIG. 1. SYNCLINAL HILL OF CRETACEOUS LIMESTONE, MEMO, PHUNG CHU VALLEY.



A. M. Heron, Photos. *G. S. I. Calcutta.*

FIG. 2. EASTERN END OF TSIPRI RIDGE, SHOWING FOLDED CRETACEOUS LIMESTONES.

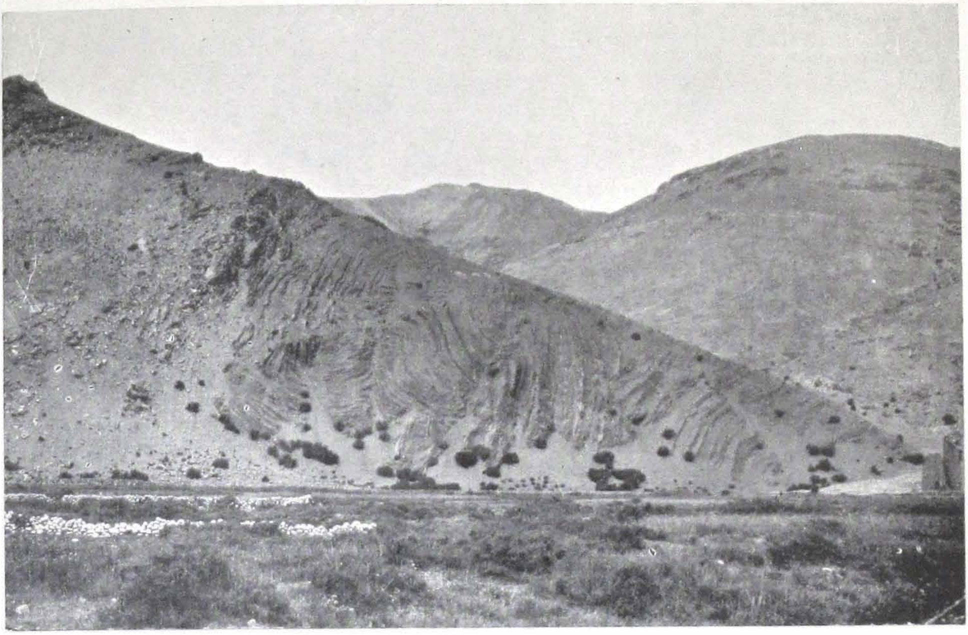
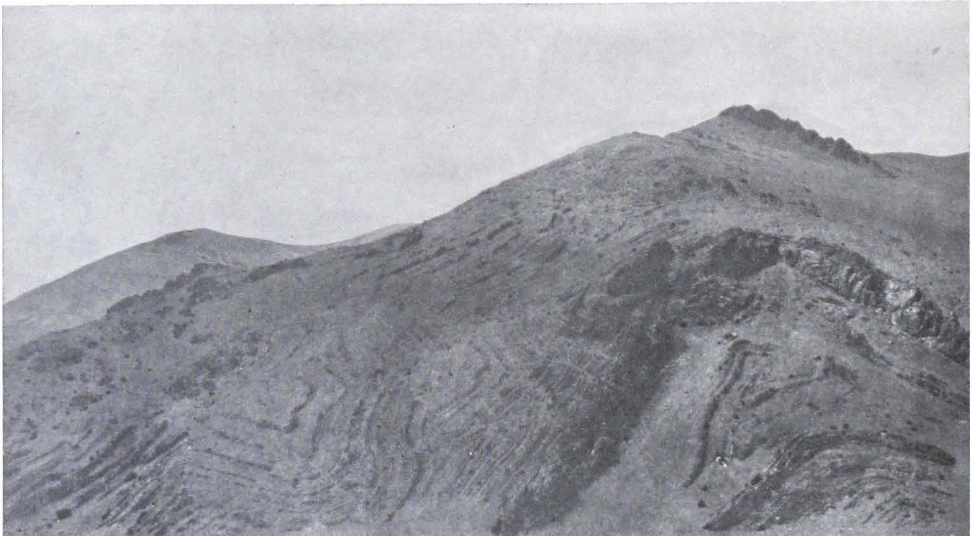


FIG. 1. FOLDED CRETACEOUS LIMESTONES, PALDING, NEAR DZAKAR CHU.



A. M. Heron, Photos. *G. S. I. Calcutta.*

FIG. 2. FOLDED CRETACEOUS LIMESTONES RIPHE, NEAR DZAKAR CHU.