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Traverses in the Himalaya.

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CONTENTS.

I. INTRODUCTION.

The following notes are the results of traverses in the Himalaya :—

(1) Kashmir and Baltistan in June and July, 1933 ;
(2) Garhwal in June, 1932 ;
(3) Nepal in portions of February, March and April, 1934 ;
(4) Sikkim in October and November, 1934.

The traverses in Kashmir and Sikkim were made when on leave, and those in Garhwal and Nepal when on duty. Captain C. E. C. Gregory, 2/18th Royal Garhwal Rifles accompanied me in Kashmir, Mr. L. B. Gilbert, I.S.E., then Executive Engineer, Kumaon Provincial Division, was with me in Garhwal, and Mr. G. B. Gourlay in Sikkim. To them I am greatly indebted not only for the benefit of their experience of travel in those parts, but for companionship and for many helpful geological observations.

Sir L. L. Fermor, Director, Geological Survey of India, has very kindly lent me his microscope slides and descriptions, together with field notes, obtained when on a traverse up the Lachen valley in Sikkim in 1911.

It is realised that there is often danger in early generalisation from incomplete observations such as are made on traverses. The Himalaya are so vast, however, that years will elapse before they are mapped geologically in detail, and it seems desirable therefore to place such observations on record, so as to build a scaffolding for the later formulation of geological structure which will eventually emerge from detailed work. Such results may also have a bearing on the understanding of the geology of the small areas where mapping is at present in hand.

Sir L. L. Fermor, Dr. Heron, Mr. Wadia and Mr. West have kindly read through this paper and suggested improvements.

II. KASHMIR AND BALTISTAN.

Previous explorers.

From the point of view of the present paper, the significant geological work has been done by Lydekker and by the geologists attached to the Italian expeditions of 1909 and 1929. My colleague, Mr. Wadia, has worked for many years in northern Kashmir and around Nanga Parbat and Gilgit, to the west and south-west of the area with which we are concerned. Mr. Middlemiss has mapped extensive portions of the mountainous area east of Srinagar. The full scientific results of the Italian expeditions, written in Italian, I have unfortunately been unable to read. I have had access only to the briefer accounts in the English language.

Route followed.

The route followed was from Srinagar, *viâ* the Sind valley, the Zoji La, the Dras, Shingo and Indus rivers to Narh, over a small col to Shigar, and up the Shigar and Braldu valleys to Askole and the Biafo glacier. The return journey was over the Skoro La to Shigar and Skardu, and thence by the Satpura route across the Deosai plains to Burzil and Tragbal. A narrative account of the excursion occurs in *Himalayan Journal,* Vol. VI, p. 67, and a description of the Biafo glacier in *Rec. Geol. Surv. Ind.*, LXVIII, pp. 400-413, (1935). The area visited is covered by Degree Sheets 43 J, M, N and 52 A, B.

1. Geological Notes.

On the cliffs E.S.E. of Matayan (34° 22′ : 75° 36′), Trias limestones are seen to occur in a well-developed recumbent fold (*see* Plate 3). This has escaped attention probably because the track lies just below the cliffs and true perspective is not obtained unless viewed from further away near the river bank. It is not improbable that some of the outcrop of Triassic limestone will yield, on detailed examination, structures of the type seen in the High Calcareous Alps of Switzerland, and the northern Calcareous Alps of Austria (Dachstein-Totesgebirge area).

These limestones rest upon Panjal traps, which are well seen at Pindras. The fact that such overfolding occurs close to the traps suggests that the contact between Trias and Panjals may be tectonic, though there is also the possibility that the Trias limestones have folded within themselves on a contact that may be normal, or only slightly disturbed.

Traps continue as far as Kharbu (34° 33′ : 75° 59′), after which begins a great outcrop of hornblende-granite. The granite is both banded and non-banded and is full of basic inclusions. At the confluence of the Dras and Shingo rivers, the banding was N.N.W. —S.S.E. A slightly more basic type is seen at the suspension bridge near Chunagund. The granite characteristically has hornblende, biotite, oligoclase or andesine and quartz, with less constant microperthite, epidote, sphene and apatite.

After Olthingthang, the granite becomes richer and richer in basic inclusions, which increase in size until along the Indus river they are sometimes several hundred yards in length. They were originally basalts and dolerites, but have been metamorphosed by the granite to epidiorites and hornblende-granulites. Smaller inclusions have often lost their igneous structure, except for occasional phenocrysts, and consist of a granoblastic assemblage of hornblende, biotite, oligoclase-andesine and sphene (miscroscope slide 23345)[1]. Specimens from larger inclusions are mostly epidiorites, the igneous structure still being discernible (23346).

Occasional inclusions of slates and quartzites show little metamorphism except for the marginal formation of hornfels. An extensive outcrop of vertical banded slates is prominent just south of Tarkuti (34° 48′ : 76° 12′), succeeded northwards by granite, which may be seen on the opposite side of the Indus river sending tongues into the slates. Near Gidiaksdo are found dark schists and gneisses, together with anthophyllite schist. Sills of granite are seen further north at Papaldo intrusive in schists, gneisses, marbles and basic rocks. Basic rocks, now hornblende-granulites, crop out at Bagicha penetrated by exogenous veins of biotite-pegmatite derived from the granite. Some of the acid material of aplitic texture is probably, however, endogenous in origin, and due to the segregation of the plagioclase from the hornblende at the time of metamorphism. It arises throughout the body or 'soma' of the rock in a manner which suggests an *in situ* source.

Hornblende-granite and metamorphosed basic and ultra-basic rocks, together with shales (opposite Kharmang), slates and quartzites crop out down to the Indus-Shyok confluence. Here biotite-granite, without hornblende, is traversed by a network of dykes and sills of basic rock, which have every appearance of being intrusive into the granite, but yet which have been metamorphosed to the customary granoblastic mosaic of hornblende, plagioclase, biotite, oligoclase, and quartz. It is possible that this biotite-granite is earlier than and was intruded by the basic rocks, and that the latter owe their metamorphism to the neighbouring hornblende-granite, which is known to be young. The biotite-granite is not itself metamorphosed, but neither are some of the argillaceous sediments caught up in the hornblende-granite. Metamorphism may have been of sufficient intensity to affect the sensitive basic rocks, but not those rocks

? Earlier granite.

[1] Registered numbers in the collection of the Geological Survey of India, Calcutta.

whose mineral assemblages are less reactive to slightly altered conditions. It should be remarked, however, that the hornblende-granite always contains biotite and that the granite in question may be simply a variety in which hornblende is locally absent. The anomaly is that the granite appears to belong to the Ladakh-Indus hornblende-granite, but yet appears also to be intruded by rocks it cannot have metamorphosed[1].

Granites continue to Ghoro-Ghone, Shigar and Tungmo (35° 28′: 75° 43′), intrusive into basic rocks, mica-schists and biotite-gneiss.

After Tungmo, follows a metamorphosed series of pelitic and calcareous rocks. Garnet-chloritoid-sericite-phyllite, diopside-actinolite-granulite, tremolite- and actinolite-schists, marbles and calciphyres are found as boulders between Alchori and Yuno, clearly having descended from the slopes of Koser Gunge mountain, 21,000 feet.

Between Yuno and Gomboro are mostly gneisses injected by veins of quartz-muscovite-tourmaline-pegmatite. It is evidently a pegmatite of this type that bears the aquamarines at Dusso. The tourmalines are often of a large size, up to 3·5 cm. in width.

The metamorphosed calcareous suite is found in force again between Pakore and Chongo (35° 41′: 75° 45′), the rock types encountered being marbles, calc-granulites, actinolite-epidote-gneiss (23350) and amphibolites, with dips to the E.S.E. These rocks probably strike southwards past Koser Gunge and down to where they were met with as boulders in the Shigar valley.

At Askole, Captain Gregory found a striking rock (rock 46/439, microscope slide 23351) which is made up of large garnets set in a matrix of kyanite, staurolite and ? roscoelite. The garnet has a specific gravity of 4·20, and is probably almandine.

East of Askole, garnet-biotite-schist, calc-granulites and rarer marbles crop out, the marble increasing in quantity, however, towards the Biafo glacier. The whole series has been invaded by a network of pegmatite dykes and sills. The dips are steep to the N.N.E. Looking E.N.E. to the Laskam col (35° 41′: 75° 57′) from near the

[1] Interesting cases are recorded by L. R. Wager from Greenland of plagioclase-amphibolite injected into an earlier grey gneiss and itself injected by pegmatite derived from the gneiss at a time of later stress and reheating. Such cases of re-injection from the biotite-granite were not noticed at the Indus-Shyok confluence, and the fact that elsewhere along the Indus the metamorphism of the basic rocks to epidiorites and amphibolites is due to the hornblende-granite makes it a legitimate conclusion that the same causes may have operated at the locality in question.

Meddelelser om Grønland; udgivne af Komm. for Videnskabelige Undersøgelser i Grønland. Bd. 105, Nr. 2, pp. 10-12, Copenhagen (1934).

southern end of the Biafo snout, there is a suggestion of a horizontal fold of marbles within the biotite-schists and -gneisses; *see* Plate 28, fig. 2 of *Rec. Geol. Surv. Ind.*, LXVIII, (1934).

Continuing up the Biafo glacier is found the same assemblage of biotite-gneiss, garnet-mica-schist, marbles amphibolites and epidosites, with dips to the south-east. A conspicuous anticline, with W.N.W.—E.S.E. axis, passes through camp 12,800 feet, north of which the dips are northerly as far upwards as the glacier was visited, about 23 miles from the snout, (*see* Plate 4). On the moraine descending north-eastwards from the first large side glacier above camp 13,570 feet were noticed the following rock types:—marble, amphibolite, biotite-sericite-schist, biotite-schist, quartz-biotite-granulite, garnet-hornblende-biotite-granulite. At camp 14,230 feet were found banded quartz-biotite-granulites often with garnet, and injected by pegmatite. Diopside is seen in large crystals up to 8 centimetres in length, together with diopside-rock (46/441) on one of the lateral moraines which descends from the eastern slope of the so-called Mount Meru.

This metamorphic series is evidently composed of a group of altered argillaceous, calcareous and silico-dolomitic rocks, associated with basic lavas or tuffs.

The main Karakoram range east of the Biafo glacier is probably composed of hornblende- and biotite-granite, since granite forms a large part of the lateral moraine on the north-east side of the glacier, which is fed by the Latok tributary. The scenery of peaks 23,900 feet, 23,400 feet and 22,790 feet is more massive and severe than that of the lesser pinnacled mountains of 20,000 feet immediately bordering the Biafo glacier, which are unquestionably built in the main of para-gneisses, and this in itself indicates a change in the nature of the rock. Desio[1] mentions that the Punmah basin is mostly cut in gneisses and granites, presumably in strike continuation with those just mentioned.

Between Askole and the Skoro La (16,640 feet) are found biotite-schists, quartz-biotite-granulites and subordinate marbles. On the south-west side of the pass occurs a less metamorphosed series of purplish quartzites, spotted schistose phyllites and dark banded slates, the latter with efflorescences of sulphates. This is probably a younger series, in which, near Shigar, Godwin Austin found crinoid stems (? Permo-Carboniferous).

[1] *Geog. Journ.*, LXXV, p. 403, (1930).

Hornblende-granite with basic inclusions is met with again just south-west of Skardu, on the way up to the Satpura Tso. Near the pass over the Deosai plains, on a hill 14,600 feet in height, occur rhyolites and tuffs. Over the pass, near a conspicuous route cairn at 14,300 feet, is a fine outcrop of porphyritic hornblende-andesite (46/430), which is not metamorphosed in spite of proximity to hornblende-granite. The volcanic rocks very probably belong to the Eocene suite of acid volcanics, serpentines, tuffs and agglomerates which Mr. Wadia has recently found on the Burzil pass. Hornblende-granite occurs throughout the Deosai plains, with occasional volcanic rocks as on the San Sangri La.

2. Discussion.

Lydekker.

Lydekker has shown on his map a syncline of Supra-Kuling rocks crossing the Biafo glacier, running east to the Skoro La, and bending south-west to Alchori, near Shigar[1]. At Shigar is marked a patch of Kuling rocks, evidently those in which crinoid stems were found. He is definite, (p. 191) that the marbles, representing his Supra Kulings, occur as a syncline conformably overlying the gneisses, which he regarded as partly Panjal in age. This view is hard to accept. Precisely where his supposed syncline of marbles crosses the Biafo glacier there is a marked anticline, with W.N.W.—E.S.E. axis, running through camp 12,800. The marbles do not form a separate series, but are an integral part of a system of ortho- and para-gneisses (interbedded marbles, mica-schists, garnet-mica-schists, biotite-gneisses, amphibolites), a fact which is well shown in Plate 4, in which the marbles are seen as pale bands between the darker schists and gneisses. It seems impossible to regard the marbles as a separate series lying synclinally upon the gneisses, partly because of the interbedding which is manifest to the eye, partly because of the presence of an anticline just where, on Lydekker's interpretation, a syncline is required. It is conceivable, perhaps, that intricate imbricate thrusting had caused two distinct sets of rocks to occur in an apparently continuous succession, but this is not the impression gained in the field. Lydekker himself states that marbles increase in frequency from Askole eastwards to Korofon, and yet separates them, partly into the gneissic group, partly in the Supra-Kulings

[1] *Mem. Geol. Surv. Ind.*, XXII, (1883).

by what appears to me to be an arbitrary line. In actuality, the impure calcareous suite is found more or less continuously eastwards of Chongo, which is nine miles west of the Biafo snout, and occurs at least as far as camp 14,230 up the Biafo glacier.

Italian expedition, 1909.

Ing. Novarese, in describing the rocks collected by the Duke of Abruzzi in 1909 from the Baltoro region, divides the sedimentary types into two series :—schists and anagenites, and a later series of dolomites, limestones and calcareous breccias. The latter he regarded as equivalent to Lydekker's Supra-Kulings, though he was in considerable doubt into which of the two series certain of the schists should be placed[1].

Italian expedition, 1929.

The last work to be mentioned is that of Desio in the recent Italian expedition to the Baltoro of 1929[2]. Only a preliminary account is available, which was given to the Geographical Society before he had fully examined his material. The succession given by Desio is—

(*d*) crystalline limestones interbedded with shales, amphibolite-serpentine, mica-schists and phyllites;
(*c*) thick shales ;
(*b*) gneissose schists ;
(*a*) augen-gneiss, injected by granite dykes.

Desio believes that there are two calcareous-schistose zones in the region :—

(1) the normal facies, fossiliferous and generally unmetamorphosed ; unquestionably Permo-Carboniferous and found especially along the Sarpo Laggo, the Shaksgam valley and in the Gasherbrum massit ;
(2) the unfossiliferous metamorphic facies of Askole and the Biaho river.

Although Desio does not actually state that he considers the two series to be equivalent, the implication throughout the paper (as, for instance, in the succession given above, in which only one group of limestones is found in the stratigraphic table) is that the metamorphic and non-metamorphic facies of limestone are of the same age. If this be accepted, it follows that the limestones of Askole and the Biafo valley are Permo-Carboniferous. His descrip-

[1] 'Karakoram and Western Himalaya,' p. 433, (1912).
[2] *Geog. Journ.*, LXXV, p. 402, (1930).

tions show that there is considerable variation in the degree of metamorphism amongst the limestones which are definitely Permo-Carboniferous.

West of the Godwin Austin glacier, the limestones form an almost continuous cover to the granite gneiss of the K2 group. This disposition is similar to that thought to exist by Lydekker just east of Askole, and might be considered to support Lydekker's contention of the synclinal disposition of a limestone series upon the gneisses. While there can be no doubt as to the existence of a great group of Permo-Carboniferous limestones, both unmetamorphosed and partially metamorphosed, at the upper end of the Baltoro glacier, and in the Sarpo Laggo and Shaksgam valleys, lying upon gneiss, I am unwilling to accept that Lydekker was correct in his supposition of a similar sequence by Askole. I would suggest that, by Askole and up the Biafo glacier, the marbles belong to the gneissic series, and that this series of gneisses, both igneous and sedimentary, has been overlain by the Permo-Carboniferous limestones in the Baltoro and neighbouring region.

D. N. Wadia.

Mr. Wadia[1], in a series of papers, has shown the presence of crystalline limestones and marbles in his Salkhala series of northern Kashmir. This series underlies proved Cambrian rocks and is therefore unquestionably pre-Cambrian. The lower Cambrian rocks of Kashmir are described as consisting of—

' a vast system of fossiliferous clays, slates, limestones and arenaceous beds.'

Salkhalas have been mapped by Wadia as far north as Rattu (35° 08′ : 74° 48′), some 70 miles to the south-west of Askole. It seems very likely, therefore, that a formation of such extent will be found also in the Biafo-Baltoro region, together perhaps with the Cambrian and lower Palæozoic. The Salkhalas of the type area are not very metamorphosed, but elsewhere a high degree of metamorphism is reached. The gneissic series of the Shigar and Braldu valleys and up the Biafo glacier, together with the associated marbles, may be for the most part Salkhala, and the whole suite may be overlain in the upper reaches of the Baltoro glacier by Permo-Carboniferous limestones. Subsequent metamorphism, involving both the older possibly Salkhala limestones and the Permo-Carboniferous limestones,

[1] *Rec. Geol. Surv. Ind.*, LXV, p. 196, (1931); LXVI, p. 218, (1933); LXVIII, p. 1 9 (1934).

would cause considerable convergence in aspect. If this interpretation is correct, Lydekker's Supra-Kulings of Askole and the Biafo would be in reality mostly pre-Cambrian and should not be correlated with the proved Permo-Carboniferous rocks of the Sarpo Laggo, Shaksgam and upper Baltoro, as is hinted by the Italian geologists. Some of the crystalline limestones in the upper Baltoro region may also belong to the older gneissic series as, for example, those of Crystal Peak, 20,088.

In all these accounts there is a disturbing association of rocks of varied metamorphic grade. Reference may be made to a portion of Desio's sequence which he describes as—

> 'crystalline limestones interbedded with shales, amphibolite-serpentine, schists mica schists and phyllites.'

This applies both to the rocks which are here thought to belong to the Salkhala series, and in a greater degree to the Permo-Carboniferous series.

The chief feature of note along the Shingo and Indus rivers is the penetration of basic lavas and intrusives by hornblende-granite, and their metamorphism to epidiorites and, hornblende-granulites. This association of granite with earlier basic rocks is found from Kharbu in the south to near Shigar in the north, and over a width from north-east to south-west across the strike of some 50 miles. Mr. Wadia has shown the same relation to exist in the south-east quadrant of sheet 43 I, and there is no doubt that the granites and metamorphic basic rocks in the two areas are equivalent.[1] Mr. Wadia has this year found an intrusive contact of the hornblende-granite with Eocene limestones and volcanic rocks, thereby proving the age of this granite to be Tertiary, a fact which had long been suspected[2]. The basic rocks belong to the Panjal volcanic episode of Permo-Carboniferous age.

Granites and epidiorites.

It is possible that there was an earlier biotite-granite intruded by the basic dykes of the Panjal episode (Shyok-Indus confluence). If this is established, it follows that the granite would belong either to an earlier plutonic phase of the Panjal igneous suite, or to an altogether earlier and distinct period of igneous activity, Caledonian or pre-Cambrian in age.

[1] *Rec. Geol. Surv. Ind.*, LXVI, pp. 222-224, (1933).
[2] *Op. cit.*, LXVIII, p. 419, (1934).

III. GARHWAL.

Previous workers.

Garhwal has been visited by several geologists. Griesbach surveyed the mountainous area of the Garhwal-Tibet frontier and Bashahr.[1] Oldham traversed in 1882 from Almora to Mussoorie.[2] Middlemiss spent several years in the foothill region, mapping the areas between the Ganges and Gungti Hill, around Naini Tal and around Dudatoli mountain.[3] Sir L. L. Fermor visited the Pindari glacier and made observations on the petrology of the gneisses.[4] In 1920 Dr. C. Fox traversed from Ranikhet to Karnaprayag and down the Alaknanda and Ganges rivers to Hardwar, in connection with the Hardwar-Karnaprayag Railway Survey. An account of a glacier in the Arwa valley by Mr. Gilbert and myself and a short paper on granites in Garhwal have already appeared.[5]

Route.

The route followed was from Ranikhet to Dwarahat, Lobah, Dewali Khal pass, Karnaprayag, Chamoli, Josimath, Badrinath, Mana, Ghastoli and up the Arwa valley to near the frontier between Garhwal and Tehri Garhwal, to a height of about 17,300 feet. Survey of India sheets 53 N/N.E., 53 N/N. W., 53 N/S.W., 53 O/N.W.

Geological Notes.

From Ranikhet to Dwarahat occurs a complex association of graphitic slates, garnet schistose phyllite, graphitic phyllitic schist, mica-schist, garnet-mica-schist and quartzite intruded by gneissose granite which is sometimes porphyritic. The same series is found again west of Lobah (30° 03′ : 79° 17′), belonging to the Dudatoli (30° 03′: 79° 12′) massif mapped by Middlemiss in 1886. Middlemiss has described the abrupt fault contact of the granite and schistose series of Dudatoli with the massive limestones to the east.[6] He states that the schistose series occurs in the form of a syncline, with dips inwards towards Dudatoli, while the rocks surrounding this series dip away from the mountain. The massive limestones crop

[1] *Mem. Geol. Surv. Ind.*, XXIII, (1891).
[2] *Rec. Geol. Surv. Ind.*, XVI, p. 162, (1883).
[3] *Op. cit.*, XVIII, p. 73, (1885); XX, pp. 26, 134, 161, (1887); XXI, p. 11, (1888).
[4] A Sketch of the Geography and Geology of the Himalaya Mountains and Tibet 2nd Edn., p. 291, (1934).
[5] *Rec. Geol. Surv. Ind.*, LXVI, p. 388, (1933); LXVI, p. 461, (1933).
[6] *Rec. Geol. Surv. Ind.*, XX, p. 162, (1887); XXI, p. 11, (1888).

out from Manwa Devi (29° 52′: 79° 25′) to Ganpurgarh (30° 05′: 79° 20′). These limestones have been mineralised. Iron is mined near Semalkhet (29° 58′: 79° 20′) and Dr. Fox has recorded that the copper mines of Dhanpur-Dobri (30° 12½′: 79° 05′) are also in limestones of the same type. Overlying the limestone with unconformity, Middlemiss describes a series of acid volcanic rocks which are themselves overlain further to the north-west by basic lavas. He referred these with some hesitation to the Deccan suite but did not at that time appear to have considered the possibility of their being Panjal or Permo-Carboniferous in age.

The basic rocks are well seen between Adbadri and Karnaprayag, and again between Karnaprayag and Chamoli. Along the Alaknanda river they appear to overlie phyllites and massive quartzites bearing a strong resemblance to the more arenaceous type of Jaunsars near Chakrata. Near Mathyana (30° 22′: 79° 18′) and Nandprayag the basic rocks are in the condition of chlorite- and hornblende-schists.

Massive limestone is found with northerly dips along the Alaknanda between miles 143 (30° 25′: 79° 24′) and 156 of the pilgrim track, dipping for the most part to the north. This is almost certainly the same limestone as that east of Lobah. The suggested succession reading downwards is—

Volcanic suite (top),
Karnaprayag and Chamoli quartzite series,
Massive limestone (bottom).

The limestone may be compared with the Deoban limestone of Chakrata, and the quartzites with the Jaunsars. Tuffs and lavas occur in the Chandpur group of the Jaunsar series, but they are not really similar to those in Garhwal and are not so abundant. Moreover, the associations of the basic rocks in the two areas are different.

From mile 158 to Josimath is a series of mica-schists and biotite-gneisses, apparently overlying the limestones and presumably thrust upon them.

Granulite series.

Northwards from Vishnuprayag (30° 34′: 79° 37′) is found a great thickness of bedded para-gneisses consisting of recrystallised quartzites, garnet-mica-schists and massive granulites containing biotite, muscovite, microcline, plagioclase, quartz and garnet. The series is characteristically arenaceous, and massively bedded. Original current-bedding structures are still preserved in spite of the complete reformation of the rocks (*see* Plate 5). The banding in fig. 2 of this plate might be explained as flow structure were it not for the fact that in larger scale views the true current-bedded nature of the cross banding is clear and certain, and flow structures are absent, as is shown by the perfect parallelism of the true bedding planes. Under the microscope, also, there is no suggestion of the rotation of garnets to form the spirals so suggestive of movement during metamorphism. The metamorphism has taken place without flow, and corresponds to the German conception of *Abbildungskristallisation.* I am not convinced, however, that the metamorphism is proved by the absence of flow structures to be post-tectonic, a corollary which is implied by Professor F. E. Suess's application of this conception.[1] Massive impure quartzites, which were the parent rocks of those now found between Vishnuprayag and Painor, would probably not flow, even if lateral stress were present.

The preservation of original bedding structures in metamorphosed rocks is, of course, a well-known feature. Recently, ripple marks have been recorded in Archæan rocks from the Grand Canyon, Colorado. Maxson and Campbell state[2] :—

'The bed in which the ripple mark occurs is a granular mosaic of quartz grains, averaging one millimeter in diameter, which appears to have been originally a well-sorted quartz sand. As a result of metamorphism the quartz grains have recrystallised and some feldspar, biotite and hornblende have been developed.'

The rock in the Grand Canyon is evidently a granulite of the same metamorphic grade as those in which the current-bedded structures are seen in Garhwal.

The dips of this granulitic series are consistently northwards from Vishnuprayag to Painor, a distance across the strike of at least 8½ miles. Taking the average dip to be 45°, there is implied a thickness of succession of approximately 32,000 feet. This is not an impossible thickness. Schuchert has described a succession of 76,000 feet on the Rocky Mountains of North America, remarking that the earth's crust must have subsided there 14 miles before it became folded into mountains.[3] There was no evidence of repetition of beds by folding or thrusting between Vishnuprayag and Painor, though it is possible that such might be forthcoming if the area were mapped in detail.

[1] *Geol. Mag.*, LXVIII, p. 78, (1931).
[2] *Am. Journ. Sci.*, XXVIII, p. 298, (1934). Reference may also be made to Sederholm, *Bull. Comm. Geol. Finlande*, No. 6, p. 98, (1899); Heron, *Mem. Geol. Surv. Ind.*, XLV, Pl. 4, fig. 2, (1917).
[3] *Bull. Geol. Soc., Amer.* XXXIV, p. 191, (1923).

At Badrinath and Mana comes in a metamorphosed calcareous suite consisting chiefly of pyroxene-granulite (44/59, 22066), marbles, diopside-calciphyres, biotite-schists and granulites, amphibolite and rusty gneiss, thoroughly invaded by tourmaline pegmatite, which sometimes bears garnet (44/66, 22073), *see* page 166.

Biotite-gneisses begin just north of the Mana falls, followed by a varied assemblage of muscovite-tourmaline-granite (fluxional and non-fluxional), muscovite-biotite-granite and streaky gneiss with biotite segregated into clusters. In the Arwa valley are found albite-oligoclase-granites, greenish in hand specimen and containing chloritised biotite. Many of the granites may be classified as adamellite. Ferruginous shales and phyllites occur on the northern lateral moraine of Glacier No. 4 in the upper Arwa valley.[1]

A pebble of fine-grained granite resembling the finer granites of the Arwa valley was found in the pre-Permian agglomerate or boulder bed (the nature of this rock has not yet been determined) at Raitpur (29° 54′ : 78° 42′). It is possible therefore that the Arwa granites are pre-Permian. It is, of course, equally possible that granites of similar type were intruded at different times and that the Arwa granites may be Tertiary, while the similar pre-Permian granite, from which the pebble was derived, has since been eroded away or covered up by later deposits.

IV. NEPAL.

Previous workers.

So far as I am aware, the only previous accounts of the geology of Nepal are those of Hooker[2] who visited the Tamur valley, near the Nepal-Sikkim frontier, in 1848, and of H. B. Medlicott[3] who visited Katmandu and the Trisuli Ganga in 1875. Hooker's descriptions are confined to an occasional mention of the rocks encountered, and to a more detailed description of the signs of earlier glaciation. Recently Mr. Sale, of the Burmah Oil Company and Dr. Sutton Bowman have visited Nepal at the request of the Nepal Government in order to undertake an economic enquiry. Both Mr. Sale and Dr. Bowman have sent to the Geological Survey of India such of the purely scientific results of their investigations as were not confidential. This present,

[1] *Rec. Geol. Surv. Ind.*, LXVI, p. 393, (1933).
[2] Himalayan Journals, 2 Vols., (1854).
[3] *Rec. Geol. Surv. Ind.*, VIII, p. 93, (1875).

account is confined to portions of Nepal east of Katmandu. It owed its inception to the results of observations made on traverses in connection with the Bihar-Nepal earthquake of the 15th January, 1934. Mention of the thrust planes which were found in Nepal has been made in the preliminary account of this earthquake.[1]

Route.

Three traverses were made in Nepal. The first was to Katmandu and the Trisuli Ganga and Indrawati rivers, sheet 72 E; the second was from Jaynagar to Udaipur Garhi, sheet 72 J; and the third from Jogbani to Dharan, Dhankuta, along the Arun river to Legua Ghat and Chainpur, over the Milke pass to the Tamur river and Taplejung, and finally up the Kabeli valley to Sabargam on the Singalila ridge and thence to Darjeeling, sheets 72 M, N, 78 A.

I. Geological Notes.

The rocks of Nepal fall into two main divisions, the Tertiary and the pre-Tertiary. Some of the granites discussed in connection with the pre-Tertiary rocks may be Tertiary in age, but they are considered together with the rocks they intrude.

(a) *Tertiary rocks.*

The Tertiary rocks are found between Amlekganj and Sanotar, over a width across the strike of 13 miles, and between Anraha (26° 49′ : 86° 23′) and Udaipur Garhi, over a width of 12 miles. They were not seen at Dharan, being covered there by alluvium. The dips are almost invariably to the north.

Going north-east from Amlekganj or from Anraha, there appears to be the same sequence :—

Middle Siwaliks,
Upper Siwaliks,
Nahans or Lower Siwaliks.

There must, therefore, be a thrust plane which separates Nahans from the underlying and younger Upper Siwaliks.

Nahans.

The Nahans are best exposed on the Udaipur Garhi ridge, and consist of the same alternations of brown-weathering sandstones and chocolate clays as occur at the type locality of Nahan itself. In addition there are

[1] *Rec. Geol. Surv. Ind.*, LXVIII, p. 217, (1934).

also thin inconstant beds of impure limestone, such as exposed 700 feet below the village of Udaipur Garhi on the western side. These limestones are evidently similar to those described by Mallet from the Nahan rocks south of Darjeeling.[1]

Similar sandstones and clays occur, but not well exposed, along the road from Amlekganj to Bhimphedi, near Sanotar (27° 28': 85° 02'). Sanotar is probably *Etoundah* of Medlicott.[2]

Middle Siwaliks.

The Middle Siwaliks form great cliffs along the Amlekganj-Bhimphedi road, near Dhukwabas (27° 19' : 85° 00'), and are found again in the neighbourhood of Muksar (26° 52': 86° 23'). They consist in the former locality mostly of sand-rock of Dhok Pathan type, full of feldspar and mica. This must be the product of denudation of an adjacent granite or gneiss terrain, possibly the western continuation of the Darjeeling gneiss complex, which may formerly have formed a more continuous outcrop from Darjeeling westwards towards the Punjab.

The rocks north of Muksar are probably a different horizon to those of Dhukwabas. The thickness of the beds of sandstones is less, seldom exceeding 50 feet. Calcareous concretions occur, and occasionally lenticles of coal, up to 2 inches in thickness and 5 feet in length. These are not worth exploiting, being rare and highly lenticular. The beds at Muksar probably represent a lower horizon of the Middle Siwaliks.

Upper Siwaliks.

The Upper Siwaliks consist of the usual conglomerates and crop out in turreted hills of the same type as in the Dun range near Dehra Dun. They are magnificently exposed at Churia Ghati (27° 21' : 85° 00'), and almost as well on the pass over the Mahamanda Danda (26° 54' : 86° 24').

The following boulders were noticed in the Upper Siwalik conglomerates in a ravine 2 miles south of Churia Ghati :—

Pale schistose quartzite ; very common	pre-Tertiary.
Purple and white quartzites	pre-Tertiary.
Dark phyllites	pre-Tertiary.
Arkoses	pre-Tertiary.
Purple and dark pebbly quartzites	pre-Tertiary.
Silty brown sandstone	probably Nahan.
Tourmaline-aplite	age unknown.

[1] *Mem. Geol. Surv. Ind.*, XI, p. 45, (1874).
[2] *Rec. Geol. Surv. Ind.*, VIII, p. 94, (1875).

The older Tertiaries are absent from the parts of Nepal which I visited. It is probable that they are only found well developed in the foothills north-west of Naini Tal.

(*b*) *Pre-Tertiary rocks.*

The sequence and correlation of the pre-Tertiary rocks of Nepal is one of great difficulty. The difficulty is increased by the intrusion of granite and granite-gneiss, and the metamorphism resulting therefrom. Two facts may be stated with certainty :—

(1) The find by Dr. Sutton Bowman of fossiliferous limestones on the Chandragiri pass (27° 40′ : 85° 11′) which are Lower Palæozoic in age. Medlicott (*loc. cit.*, p. 97) had noticed facets of calc-spar with a central puncture, which he thought might be crinoidal. From the specimens obtained, Waagen, Palæontologist of the Geological Survey, was unable to give a definite opinion as to whether or not they were organic.

(2) The continuation of the Darjeeling gneiss and the Daling series westwards from Darjeeling into Nepal.

The rocks of Dhankuta-Chainpur, of the Mahabharat Lekh near Udaipur, and of the Sheopuri Lekh north of Katmandu are unquestionably, in my opinion, Darjeeling gneiss. The underlying phyllites of Taplejung (27° 21′ : 87° 40′), Mulghat (26° 56′ : 87° 20′), Deopur (27° 45′ : 85° 34′) and near Nawarkot (27° 55′ : 85° 11′) may be regarded as Dalings. There is no doubt at all with regard to the correlation of the phyllites at Taplejung, and Mulghat, and a very fair certainty about those north of the Nepal valley.

A thrust plane separates the pre-Tertiaries from the Tertiaries just north of Sanotar (27° 28′ : 85° 02′). The former series consists of the following types, going northwards :—carbonaceous phyllites; schistose sericite-quartzites (one mile south of Bhainse ·Dobhan), with dips to the N.N.E.; marbles at Bhainse Dobhan, with dips northwards at 70°; phyllites at Golping. From Bhimphedi up to the Sisagarhi col is an extensive series of schistose sericite-quartzites, tuffaceous quartzites, fine-grained biotite-granulites, biotite-schists, chlorite-biotite-schists and sheeny puckered phyllites, injected with occasional veins of tourmaline-aplite. Rock 46/414-23326 is a muscovite-

Bhimphedi-Katmandu.

tourmaline-oligoclase-quartz-aplite intruded against garnet-muscovite-biotite-quartz-granulite. Overlying this mainly arenaceous group of rocks is porphyritic muscovite-granite which is found on the path from Sisagarhi col down to Kulikhani. This granite (46/412-23324) contains tourmaline, muscovite, less common biotite, orthoclase with microperthite, and albite, and is clearly the source of the aplite veins descending into the underlying arenaceous rocks. Above the granite is found a group of quartz-biotite-granulites, schists, phyllites, calc-granulites, and marbles in beds up to five feet thick. At a height of about 5,400 feet on the path up to the Chandragiri pass may be seen large nodules of marble, up to 3 feet 8 inches in thickness, embedded in puckered talcose and chloritic phyllites. These nodules are strongly reminiscent of those found in the Rohtas limestone group of the Vindhyan rocks along the Son valley,[1] except that the Nepal rocks have been subjected to some degree of metamorphism.

Chandragiri fossiliferous limestones.

On the south side of the Chandragiri pass about 50 yards below the summit occur the blue-grey non-metamorphosed limestones in which Medlicott, Bowman and I found fossils. A preliminary examination, by Mr. Lahiri, of the fossils in Bowman's collection shows the presence of the following organisms :—

Cystoid calyx (incomplete) and detached calyx plates;
Brachiopod valves (incomplete) with radial sculpture, probably *Orthis* ;
? Bryozoa, indistinct fenestellid incrustations ; Crinoid stems.

These fossils are definitely Palæozoic and probably Ordovician in age. Descending into the Nepal valley occur quartzites underlain by ripple-marked purple and green phyllites, and slightly metamorphosed banded shaly and sandy limestones, a facies again similar to some in the Semri series of the Vindhyan system along the Son valley.

Nepal valley.

Most of the Nepal valley is covered by fluviatile and lacustrine sediments :—clays, sands, conglomerates and lignite beds. A fossil femur bone of an elephant has recently been found. The rocks probably range in age from Pliocene to recent. The underlying older rocks are chiefly quart-

[1] *Mem. Geol. Surv. Ind.*, LXII, Pl. 9, fig. 1, (1933).

zites, quartz-schists and calcareous sandstones (Dubrinipani and Pashupatinath); biotite-schists and granulites with occasional dykes of pegmatite, (Nagarkot spurs).

On the north side of the Nepal valley, five miles north-west of Katmandu, is found gneissic granite and tourmaline-pegmatite containing abundant inclusions of biotite-schist and rarer quartzite, tuffs and hornblende-schist.

Trisuli Ganga.

The Sheopuri Lekh is built of a syncline of muscovite-gneiss with tourmaline, calc-granulites (Kaulia, 27° 49′: 85° 15′), quartz-biotite-granulites and biotite-schists. Going down the spurs on the north side, the metamorphism is seen to become less. At a height of 2,850 feet, near Thansing Mukhi Jor, crinkled phyllites and thin-bedded quartzites occur interbedded with mica-schists. Still lower down, phyllites predominate. At the valley bottom almost unmetamorphosed limestones occur in association with ferruginous phyllites (near Ganrkhar and Dhanphedi). Phyllites and phyllitic schists are found up the Trisuli Ganga as far as Betrawati (27° 59′ : 85° 11′).

Indrawati valley.

The eastern termination of the Darjeeling gneiss of the Sheopuri Lekh syncline is met with on the path down to the Indrawati river to Sipa Ghat (27° 45′: 85° 37′). Gneiss, biotite-schist and schistose quartzite are the chief rock types until the underlying phyllites appear near Deopur, sometimes containing garnet. Phyllites continue down as far as the Indrawati. I was not permitted to cross the river, but the rocks on the other side are darker and probably belong to a different series, perhaps faulted or thrust against the phyllite and gneiss groups.

Summary of relationships in sheet 72 E.

Summarising the relationships of the rocks seen in the traverse of sheet 72 E, the succession appears to be in ascending order:—phyllites at the base; quartzites, phyllites and granulites; marbles and metamorphosed sandy limestones, together with granulites and schists or phyllites; the Chandragiri limestone of probable Ordovician age. The succession is completed by the intrusion of the Kulikhani, granite, south of the Chandragiri pass, and of the orthogneisses and pegmatites of the Sheopuri Lekh. The complex of ortho- and para-gneisses of the Sheopuri Lekh is similar to the Darjeeling gneiss of Sikkim and eastern Nepal.

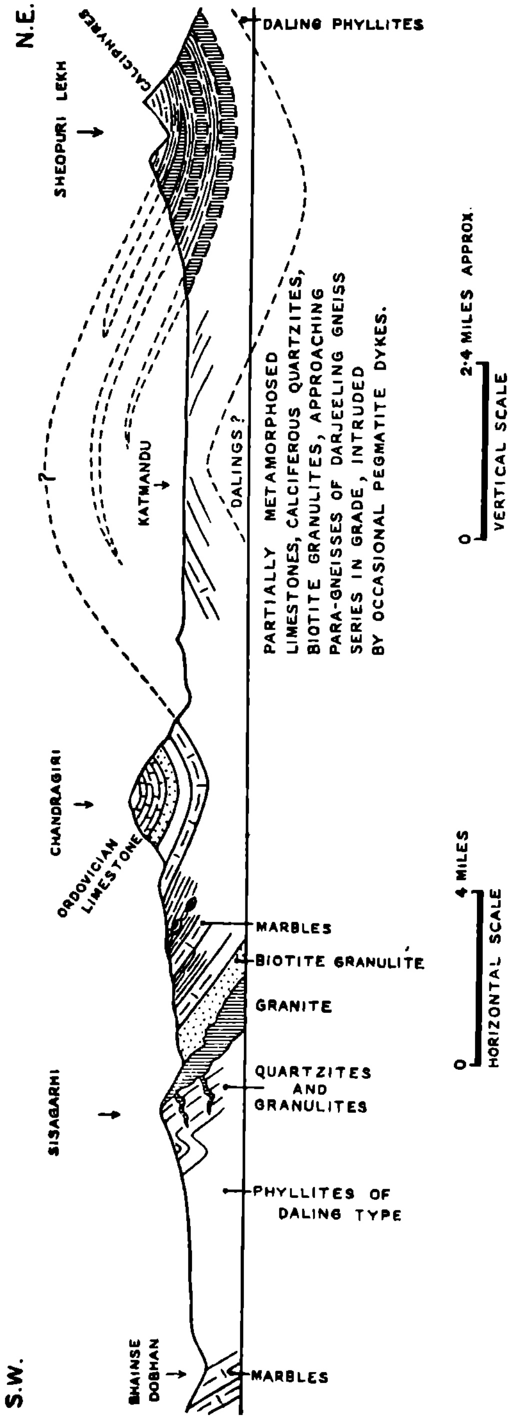


FIG. 1. Diagrammatic section across the Nepal valley in sheet 72 E.

The relationships of the rocks at Udaipur Garhi (26° 57′: 86° 32′) are best illustrated by the diagrammatic section given below. The schists, granulites, quartzites and calc-granulites are similar to those of the Darjeeling gneiss and to those of the Sheopuri Lekh north of Katmandu. Immediately above the Nahans occur bleaching carbonaceous phyllites, overlain by thin-bedded siliceous limestones and finally by dark banded limestone with patches of white marble due to low-temperature stress (the bulk of the limestone has not recrystallised). Separating the limestone from the schist-gneiss series is a graphite band, evidently marking the line of a thrust plane. This limestone is very similar to the dark stinking limestones of the Upper Krol stage. The association of carbonaceous phyllites with an overlying dark limestone recalls the similar sequence along the Krol belt of the United Provinces and it may be mentioned that their disposition relative to the Nahans is the same in the two areas.

Udaipur Garhi; 72 J.

In 1931 Dr. Bowman found crushed Gondwana coals 36 miles to the east, just south of the junction of the Sun Kosi with the Arun river[1] (26° 55′ : 87° 09′).

North of Dharan (26° 49′ : 87° 17′) are found green and purple slates and phyllites, succeeded upwards by vitreous quartzites on the Mahabharat Lekh. The phyllites crop out again north of the ridge, together with bands of ferruginous limestone. These outcrops are only some 10 miles E. S. E. of the coal-bearing Gondwanas found by Bowman, and are in approximate strike continuation with them. Boulders of garnet-mica-schist and gneiss in the Loti Nala prove that the gneiss-schist series is found somewhere *in situ* near hill 6350 (26° 53′ : 87° 23′).

Dharan Bazar; 72 N.

On the track up from Mulghat to Dhankuta (26° 59′ : 87° 21′) carbonaceous slates and sheeny phyllites, with bands of impure siliceous limestone, pass upwards to phyllitic schist containing occasional garnets (2,280 feet on path) and finally to mica schists (2,500 feet) and quartzite (3,050 feet). North of Dhankuta, mica-schist occurs associated with ortho- and para-gneiss.

Dhankuta; 72 N.

Across the Buranse Dande, on the path down to the Arun river and Legua Ghat, occur gneiss at 3,700 feet and biotite-granite at 3,500 feet. Still further below occurs a conspicuous band of marmorised limestone associated with

Arun valley; 72 M.

[1] *Mem. Geol. Surv. Ind.*, LIX, p. 42, (1934).

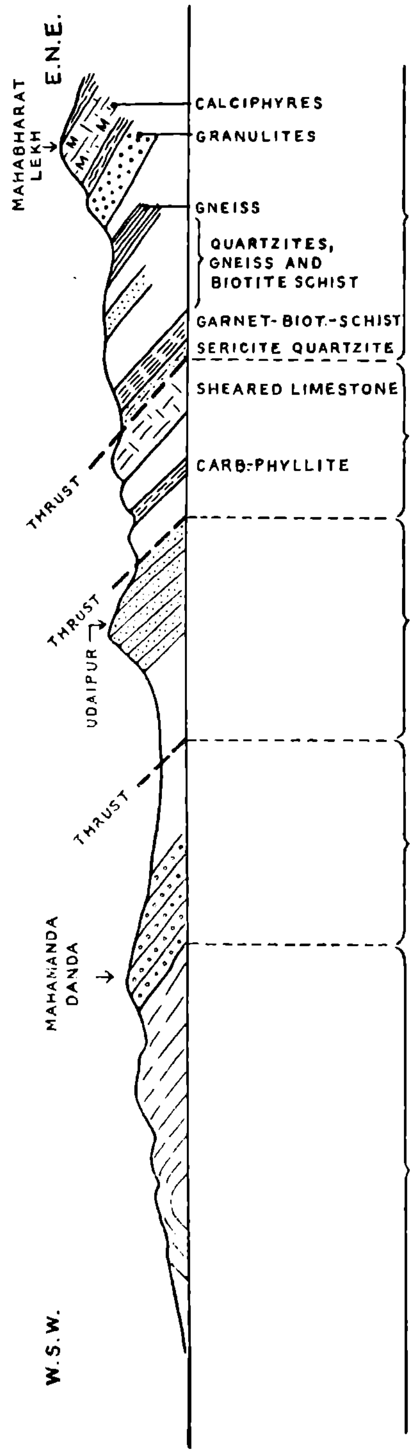


FIG. 2. Diagrammatic section through Udaipur Garhi in sheet 72 J. (Approximate length of section is 14 miles. Not to scale.)

chloritoid-garnet-phyllite (46/426-23338), calc-phyllite and talcose phyllite. This calcareous band strikes down to the Mangme Khola, and crosses the Arun river about two miles south of Legua Ghat. The dips swing round from north-east to east and then to E. S. E. The same calcareous band is almost certainly found again four miles south of Chainpur (27° 17′: 87° 18′) in the form of saccharoidal marbles, calciphyres, tremolite-rocks, epidote and garnet-biotite-schists, and recrystallised quartzites. This band appears therefore to have passed from the phyllite or chlorite zone (chlorite is the characteristic mineral of these phyllites), into the schist zone, represented by higher grade minerals such as biotite and garnet. Near Piple, the band would be classified in the Daling series, and south of Chainpur in the Darjeeling gneiss.

Milke pass ; 72 M.

Garnet-mica-schist, quartzite, and banded ortho- and para-gneisses occur continuously from Chainpur eastwards to the Milke pass. Specimen 46/421-23333 is typical of the garnet-gneisses and contains muscovite, biotite, oligoclase, quartz and garnet. Kyanite-schist occurs near Nundhaki, but was not found *in situ*. Calciphyres, pyroxene-granulite and marbles are found as boulders in the Pilua Khola, having descended from outcrops one mile north of Nundhaki.

Tamur and Kabeli valleys ; 72 M.

In the Tamur river, a return is made to chlorite-sericite schistose phyllites; typical Dalings. Such rocks are found at Taplejung and eastwards as far two miles west of Yektin (27° 12′ : 87° 54′), where they underlie and pass up into Darjeeling gneiss. This gneiss continues all the way to Darjeeling. In the neighbourhood of Yektin, Memeng and Phedi, the gneiss series consists of the characteristic banded garnet-gneiss (46/422-23334), with less abundant calciphyres and garnet-amphibolite. A good section is seen where the path crosses the *nala* just below Yektin.

One other feature of interest may be mentioned. Within the Daling phyllites is a thick sill of highly sheared tourmaline-granite which occurs in a dip slope from the Angbung (27° 16′ : 87° 44′) ridge northwards down to the Kabeli river, (46/424-23336). This is made up of shattered tourmaline, bent muscovite, feldspars which have completely broken down to a felt of sericite and quartz, and patches of quartz mosaic with marked strain shadows. This granite has evidently been sheared in the cold, subsequent to intrusion.

There appears to have been very little metamorphic effect on the intruded phyllites.

2. Thrust Planes.

Three thrust planes have been recognised in Nepal. One separates the Nahan, or Lower Siwalik rocks from the underlying Upper Siwalik conglomerates. It occurs near Hitaura (27° 26′ : 85° 02′) and again near Nepaltar (26° 54′ : 86° 32′). This thrust cannot be older than Pliocene. The so-called 'main boundary fault', which separates the pre-Tertiaries from the underlying Lower Siwaliks, is found just north of Sanotar (27° 28′ : 85° 02′), again on the first col E.N.E. of Udaipur Garhi (26° 56′ : 86° 32′) and probably continues through Dharan Bazar to pass below Tindharia on the Darjeeling-Himalayan Railway. A third thrust was seen 1·6 miles E.N.E. of Udaipur Garhi, and marks the boundary between the garnet-schists of the Darjeeling gneiss and the underlying possibly Krol rocks.

3. Discussion.

Certain points may be summarised. Firstly, the Dalings and Darjeeling gneiss, which occupy a large part of eastern Nepal, owe their present disposition to large scale warping and folding, the gneiss occurring in the cores of the synclinals. North of Katmandu, the Sheopuri Lekh syncline has an east-west axis. Along the Arun and Tamur rivers the warpings have N.N.E.-S.S.W. axes, the Dalings cropping out in the Tamur anticline and the gneiss in the Dhankuta syncline. These broad warps may be compared with the warp mapped by Mallet and Bose in Sikkim. There are in addition minor folds, such as the anticline which crosses the Dhankuta synclinal warp with an east-west axis a little to the south of Chainpur.

Secondly, the upward passage from Dalings into the overlying Darjeeling gneiss appears to be gradual rather than abrupt, as was first noticed in Sikkim by Mallet and later by Bose. Evidence has been cited from the Arun valley of the transgression of a calcareous band from the chlorite zone to the biotite-garnet zone. To some extent, therefore, the terms Dalings and Darjeeling gneiss may represent metamorphic grades rather than stratigraphical series. The increase in metamorphism upwards must have some connection with the occurrence in this direction of *lit par lit* intrusions of granite and granite-gneiss. Dr. A. M. Heron had independently come to the same conclusion as a result of his traverse through

Sikkim with the Everest Reconnaissance Expedition in 1921. This question will be discussed again in a later section (*see* page 161).

Thirdly, there is the question of the age of the granite intrusions and of the metamorphism in Nepal. The Chandragiri limestone, of probable Ordovician age, occurs in a syncline resting upon rocks which show an increase in metamorphism downwards. Until detailed mapping is carried out, it is impossible to state whether the Chandragiri limestone lies conformably or unconformably upon the underlying phyllites, marbles and granulites. Should the junction be a conformable one, the Kulikhani granite would be Ordovician or post-Ordovician in age. Should there be an unconformity, this granite would be pre-Ordovician, unless an accident of intrusion resulted in a young granite just failing to reach the unconformable junction with the overlying limestones.

South of the Chandragiri pass, the metamorphism seems to be transitional in type between regional and thermal, and certainly to be connected with the intrusion of the Kulikhani granite and related aplites and pegmatites. Along the Sheopuri Lekh, the metamorphism is more of regional type, and it is more difficult in this case to assess the importance of the rôle played by ortho-gneiss in the metamorphism. In the case of the Angbung granite (sheet 72 M), which is intrusive into Daling phyllites, there is very little accompanying metamorphism. It remains uncertain whether all the rocks considered above were metamorphosed to varying degrees at one time, or whether later granites have caused local convergence in metamorphic type, *e.g.*, south of the Chandragiri pass, to an earlier series of regionally altered rocks such as those of the Sheopuri Lekh.

V. SIKKIM.

Previous workers.

The chief geological work in Sikkim was carried out by Mallet,[1] and Bose.[2] Important observations have been made by Hooker[3] Garwood,[4] Hayden,[5] Fermor,[6] Heron,[7] Dyhrenfurth,[8] and Wager.[9] In 'Everest 1933'

[1] *Mem. Geol. Surv. Ind.*, XI, Pt. 1, (1874).
[2] *Rec. Geol. Surv. Ind.*, XXIV, p. 217, (1891).
[3] 'Himalayan Journals', 2 Vols., (1854).
[4] 'Round Kangchenjunga', p. 275, (1903).
[5] *Mem. Geol. Surv. Ind.*, XXXVI, Pt. 2, (1907).
[6] *Rec. Geol. Surv. Ind.*, XLII, p. 91, (1912).
[7] *Op. cit.*, LIV, p. 215, (1923).
[8] 'Himalaya; Unsere Expedition', pp. 293-311, (Berlin, 1931).
[9] 'Everest 1933', pp. 312-336, (1934).

Wager has written a valuable summary of the geology of the Everest region and northern Sikkim, including certain tentative correlations between the rocks on the northern and southern borders of the Himalaya.

Route.

The routė followed was from Gangtok up the Lachung Chu to Mome Samdong (27° 55′ : 88° 42′), and the Sebo La pass; up the Sebo Chu to a camp at a height of 16,500 feet (approximately 27° 54′ : 88° 49′); and *via* the Lachen Chu and Tso Lhamo to a hill of 21,000 feet on the north-east side of Pauhunri (27° 57′ : 88° 51′). Survey of India Degree Sheets 77D-78A.

I. Geological Notes.

(*a*) *Dalings and Darjeeling Gneiss.*

Gneiss persists from Gangtok almost to the Penlong La. From here to near mile 20 on the Chungtang road crop out phyllites and phyllitic schists for the most part typical of the Dalings and characterised throughout by the presence of chlorite, either disseminated uniformly through the body of the rock, or in some cases both as porphyroblasts and in the ground mass. Dips are to the north-east. Wager has mapped Tertiary granite from Gangtok to near Dikchu, which is presumably the gneiss seen between Gangtok and the Penlong La. At Mangen, these chlorite rocks give place to garnet-biotite-schists and these in turn to gneiss just east of Singhik, the dips being uniformly to the north-east. Gneiss persists from near Singhik as far north as the peaks of Chomiomo, Kanchenjau and Pauhunri, and is made up of a complex of ortho- and para-gneisses, the whole invaded by granite, pegmatite and aplite. In the igneous group may be placed the common augen-gneisses as described by Freshfield and Dyhrenfurth and many of the rusty banded gneisses such as occur some 2 miles east of Singhik, on the cliffs west of Lachung (27° 42′ : 88° 45′) and near Dunkung or Deutang (28° 01′ : 88° 36′). There is in addition a great variety of sedimentary gneisses including calcareous and quartzitic facies.

Calciphyres, pyroxene-granulites and biotite-granulites are found at the following localities:—

(1) one mile west of Nanga and nearer Tong, dips to the north-east;

(2) one mile north-east of Chungtang, cropping out both in the Lachen and Lachung valleys, dips north-east;
(3) from the angle between the Zemu and Lachen valleys southwards to west of Chotang, dips east, west and vertical;
(4) in the Sebo Chu valley at about a height of 15,000 feet on the west side of the Khönpuk glacier (27° 53′ : 88° 50′), dips south-west.

The first three of these occurrences have been recorded by Hayden and Fermor.

Quartzites are seen most prominently at the confluence of the Lachen and Lachung Chus, at Chungtang, striking from near Latong Tenga to the neighbourhood of the Black Rock, the dips being N.N.E. They are also found in the Teesta valley three quarters of a mile north of Tong.

The broad distribution of the rock groups is as follows. A zone mainly of para-gneisses, including the two facies mentioned above, and approximately 11 miles in width, runs S.E.-N.W. from about Chumunko (27° 27′ : 88° 48′) to Lama Anden or Lamgebo (27° 45′ : 88° 30′). North of Lachen a prominent syncline is seen particularly at Yatung, running north-south, so that it is clear that the N.W.-S.E. direction of strike does not persist for long. These para-gneisses are apparently overlain by rusty banded biotite-gneiss and augen-gneiss, which are very probably of igneous origin. Such rocks are well seen for the first ten miles up the Sebo Chu valley, from Lachung to Mome Samdong and from about Potago in the Lachen valley up to Deutang and the Gayabo lake. Another outcrop of para-gneisses occurs in the upper Sebo Chu valley, with dips to the south-west, under the ortho-gneisses. Still further to the north occur what are probably interbanded ortho- and para-gneisses with a general dip to the north, as on the Tibetan slopes of Chomiomo and Pauhunri. These rocks are clearly highly folded, as may be seen in the great overfold between what is probably Survey of India Peak No. 109 (22,960 feet) and the peak next to the south-east (*see* Plate 6). Viewed from the south, this appears to be a horizontal fold with a flat axial plane, but the impression of horizontality may be due to overfolded beds, with a northward-inclined axial plane, cropping out upon a nearly vertical precipice wall. The complexity of folding on the Sebo wall suggests that the succession will be very difficult to unravel. Broadly speaking, however, the para-gneisses dip under the ortho-gneisses.

In north-east Sikkim the general strike is N.W.-S.E., but it is certain that this strike is local, and changes westwards, probably to east-west.

Granite, pegmatite and aplite.

Thin veins of aplite begin to be noticeable in the gneisses at Tong bridge. They become conspicuous at Chungtang, one in the Lachen Chu being a foot in width, and increase in importance northwards. On the northern slopes of Chomiomo, around the Sebo La pass and on the precipices north and west of the upper Sebo Chu valley the gneisses become riddled with bosses, thick dykes and sills of fine-grained white granite. This granite cuts across the folds of the gneisses and is therefore later than the folding. The complexity of intrusion is well displayed on the flat-topped glaciated ridge of about 17,000 feet running on the north side of the uppermost Sebo La lakes. Flaggy ferruginous gneiss and quartz-granulite are easily demarcated from the white granite which weathers into large polygonal boulders. While most of the granite is clearly discordantly intrusive, there is little doubt that some of it has sometimes penetrated the gneisses in a *lit par lit* fashion, even in bands as narrow as one centimetre in width. One concordant contact on a large scale is seen in a corrie at about 16,500 feet on the west side of the Upper Sebo Chu valley, where the granite ends abruptly against the flat surface of the overlying gneisses. The discordant contacts are, however, the more characteristic and are proof that this granite is distinct from and younger than the gneiss series, (*see* page 165).

Microscopical.

The young granite is a fine-grained white granite without flow structures (46/882-23692, 23694). Under the microscope it is seen to consist of biotite, generally muscovite, oligoclase, orthoclase and quartz, and with tourmaline, pink topaz, rutile and occasionally sillimanite as accessories. The topaz is often seen in hand specimen in small pink prisms. Hayden mentions the presence of beryl in the pegmatites of the Lachen valley[1]. The only exceptional mineral in my specimens is topaz. Where tourmaline is common the biotite has generally been chloritised. In the Sebo Chu valley the tourmaline is frequently found to occur in spherical clusters, up to 5 cm. in diameter, with a biotite-free reaction rim one centimetre in width, (46/883-23693). Plagioclase is in excess of orthoclase. The aplites show the same

[1] *Mem. Geol. Surv. Ind.*, XXXVI, Pt. 2, p. 59, (1907).

assemblage of essential minerals, except that the orthoclase appears to be commoner, (46/884-23695).

The quartzites near Chungtang very generally contain sillimanite (46/908-23702, also Sir L. L. Fermor's slide No. C-54), and sometimes a green mica which may be fuchsite (46/888-23701).

The pyroxene-granulites contain augite or diopside, sphene, andesine or labradorite, orthoclase, microcline, and quartz. In the calciphyres occur free carbonate, together with subordinate diopside, tremolite, biotite, andesine or labradorite, orthoclase, sphene, pyrites. In 46/886-23698 the dominant ferro-magnesian mineral is hornblende.

The pelitic rocks of the Dalings are best exposed between the Penlong La and Dikchu. The type rock is a green chlorite-sericite-quartz-phyllite grading into schist (23703). Nearer the overlying gneiss it developes into a coarser schistose phyllite with porphyroblasts of chlorite. Specimen 46/889-23704 is a garnet-biotite-chlorite-sericite-schist. It may be remarked that both in Nepal and in Sikkim garnet frequently occurs in chlorite-sericite rocks. Some, but not all, of these rocks may be retrograde. Rock 46/889 shows the marginal breakdown of garnet and the chloritisation of the biotite. Sir L. L. Fermor had previously collected, from about the same locality, an altered staurolite-mica-schist which shows the sericitisation of the staurolite and the biotite altered to chlorite (C-39). The fact that these rocks occur in the vicinity of copper lodes suggests that the retrogressive change may be hydrothermal and connected with local mineralisation. Those who postulate a thrust between the Dalings and the Darjeeling gneiss would probably claim that such changes indicate low-temperature stress and the existence of a thrust. This question is discussed on page 162.

(*b*) *Lachi series.*

Wager[1] has described the finding of Lower Permian brachiopods in what he has termed the *Lachi* series : a complex association of quartzites, limestones, hardened shales and pebble beds. When I was on leave in England in 1933 he kindly showed me specimens of the pebble beds, which in hand specimen and under the micros-

[1] 'Everest 1933', p. 333, (1934).

cope resemble the Blaini tillite of the Simla-Mussoorie foothills. The pebbles he collected from these beds were of the following kinds :—

Darkish quartzite,
Quartzites, some rich in detrital tourmaline,
Pink limestone,
Sericite tuff or rhyolite,
Muscovite-granite.

This year Gourlay and I found a similar boulder bed, presumably from about the same locality (28° 01′ : 88° 45′), on the west side of Lachi hill and east of the Gordamah lake. The pebbles were rare. The matrix is a dull green-brown grit, composed of completely ungraded angular quartz grains, with subordinate microcline and sodic plagioclase set in a very fine brown paste full of sericite, biotite and quartz, (46/909-23705). It shows a striking resemblance to the green silty sandstones of the Talchirs in the peninsular Gondwana coalfields. The microscope suggests that the rock is either glacial or pyroclastic in origin. The significance of this will be discussed in Section VI, (*see* page 155.)

(c) *Tso Lhamo series.*

At the foot of a gully on the east side of Lachi hill, at about a height of 17,300 feet, and at bearings of 74° to the northern end of Tso Lhamo, 130° to Pauhunri and 157½° to the Dongkya La, we found dark limestones and shales with a rich fauna of ammonites, lamellibranchs, and brachiopods. The position of the locality is about Lat. 28° 02′ N : Long. 88° 46′ E. (*see* Plate 7), and the dip of the strata is 20° to the E.S.E. This fauna has not been examined in detail, but my colleague Dr. M. R. Sahni believes it to have Triassic affinities. The final determination of age must rest on the results of a detailed palaeontological examination, but it seems clear that the fossils indicate that the beds are pre-Jurassic and probably post-Permian. They are younger, therefore, than the Lachi beds of Wager, which also they overlie in stratigraphical sequence. Underlying the richly fossiliferous beds are about 300 feet of grey gritty flags containing uncertain plant remains.

Along a ravine running N.N.E. of Pauhunri 23,180 peak, occurs a series of flags, limestones and clay-slates. A lamellibranch resembling *Daonella* was found at about 19,400 feet. The flags are very similar to those underlying the richly fossiliferous Tso Lhamo limestones, and like them contain doubtful plant impressions. Underlying these beds, and cropping out on hill 21,000 feet, north-east of Pauhunri, are dark blue shattered limestones which are very probably the same as the Upper Everest limestone of Wager. This limestone and associated shales overlie the gneiss of the Pauhunri massif. I have little doubt that the beds on the north-east side of Lachi hill, and those of the Pauhunri ravine are equivalent. It is very probable also that the fossiliferous limestones north-east of Tso Lhamo found by Hooker in 1850 belong to the same series, and may be Triassic. I agree with Wager that Hooker's limestone is not the same as the Upper Everest limestone. We passed the former on the way down from Pauhunri, but fatigue and mild frostbite prevented us from delaying there.

I would suggest the designation *Tso Lhamo* for these probably Triassic beds, a name beautiful in itself, and given to a lake the position of which is one of the fairest in the world.[1] They fill a gap between the recently discovered Lachi beds and the Jurassic system which has long been known to cover so much of Tibet.[2]

(*d*) *Probable uninversion of Tibetan sedimentaries on Himalayan gneiss.*

Dyhrenfurth has called a succession of beds in north-west Sikkim 'von mehreren tausend Metern Machtigkeit' the *Dodang* series.[3] They consist of limestones, limestone breccias, calcareous shales, phyllites and sandstones, with indeterminable fossils. The age of these beds cannot be determined by reference to the fossils, but by lithological comparison with the Mesozoic rocks of the Alps, Dyhrenfurth claims to have found a complete succession of Trias, Jura and Cretaceous. He states also that this succession has been overthrust in inverted position, with the Trias uppermost, upon the Kanchenjunga gneiss. He admits that lithology is not always a safe guide, but questions whether a series of such thickness could belong to a single formation.

Only 35 miles to the east we have the following succession :—

Jurassic rocks of Tibet ;
Tso Lhamo series, probably Trias ;
Lachi series, probably Lower Permian ;
Everest limestone ;
Gneiss of Chomiomo, Kangchenjau and Pauhunri.

[1] Tso Lhamo = Lake Goddess.
[2] *Mem. Geol. Surv. Ind.*, XXXVI, Pt. 2, (1907).
[3] 'Himalaya : Unsere Expedition', pp. 301-303, (Berlin, 1931).

This is a normal, uninverted succession. The Everest limestone is certainly very shattered, and may owe its deformation to a thrust between the unmetamorphosed sedimentaries and the underlying gneiss, though Wager does not accept that even a thrust is present. But the fact that a normal succession occurs in north-east Sikkim, either autochthonous or thrust upon the gneiss, is an indication that Dyhrenfurth may be incorrect in supposing an inverted sequence on the Dodang Nyima range. His conclusions are based upon uncertain evidence.

VI. DISCUSSION.

In spite of the fact that these observations are based only on traverses and not on detailed mapping, thereby lacking the greater certainty which the latter would provide, yet there are features which have appeared from them and from the observations of other geologists that require discussion. I have already discussed the observations made in the Karakoram as far as is legitimate from their cursory nature. The Karakoram form a separate geographical unit and are best considered independently from the more homogeneous outer Himalaya between Garhwal and Sikkim. What follows concerns chiefly Garhwal, Nepal and Sikkim.

1. Relics of Peninsular India in the Himalaya.

(a) As indicated on general grounds.

Gondwana relics.

It has long been known that coal-bearing Gondwana rocks occur in the Darjeeling and Assam foothills. More recently Dr. Fox has been able to identify a boulder bed just above Tindharia station, which may possibly be glacial. Dr. Fox has also observed, near Tindharia and along the Teesta valley, further outcrops of the intrusive lamprophyres and mica peridotites that form such a characteristic feature of the Bokaro, Jharia and Raniganj coalfields.[1] Sutton Bowman found coal-bearing Gondwanas in eastern Nepal at the confluence of the Sun Kosi and Arun rivers. The Gondwana rocks of Kashmir are well known through the work of Middlemiss, Bion and Wadia, and

[1] *Mem. Geol. Surv. Ind.*, LIX, p. 50, (1934).

they do not require further description. They afford proof that the Gondwana formation spread far to the north over part of what is now the Kashmir Himalaya, and has been involved in the Himalayan folding.

As stated above, Wager in 1933, and two of us in 1934 found boulder-bearing beds associated with Lower Permian rocks on Lachi hill, north of the Himalayan range. 35 miles to the south-east of Lachi, in the neighbourhood of the Ammo Chu and Phari Dzong, occurs the Dothak series of Hayden. This consists of a lower series of limestones with arenaceous and argillaceous beds above. Wager correlated these rocks with the Mount Everest limestone series. Dr. Fox wrote in connection with them[1]:—

'Seeing that they occur on the Indian side of the Himalayan range and that an Anthracolithic fauna has been discovered in the Eastern Himalaya in the Abor country it is quite possible that the Dothak series may contain representatives of the same rocks. They would then continue the line of Permian and upper Carboniferous outcrops which evidently stretch from Moulmein and the Shan Plateau through the Abor hills to the Central Himalaya and Kashmir to the Punjab Salt Range.'

Westwards of Sikkim, boulder beds are also found along the peninsular border of the United Provinces and Punjab Himalaya, including the breccia of Garhwal (? glacial or volcanic), the Mandhali beds and the Blaini boulder bed. The Talchir glacial boulder bed of the Salt Range is well known. Wadia has found striated boulders in the Tanakki boulder bed of Hazara, near Abbottabad, and has therefore confirmed the suggestion put forward by Oldham, and later by Middlemiss, that the boulder bed is glacial and equivalent to that of Talchir.[2]

Most of these boulder beds are of glacial origin, though there is doubt in some cases as to what extent volcanic agglomerates may not be included in that type of sedimentation (Lansdowne area of Garhwal). The association of such beds on Lachi hill in northern Sikkim with possible plant-bearing strata is analogous to the definite association of plant-bearing Gondwana rocks with the Talchir boulder bed in the Indian Peninsula, and is some indication that the origin of the Lachi pebbly grits is glacial rather than volcanic. Their resemblance to the Talchirs is certainly very striking. Accepting a glacial origin for these beds it follows that the great Gondwana

[1] *Op. cit.*, LVIII, p. 62, (1931).
[2] *Rec. Geol. Surv. Ind.*, LXII, p. 153, (1929); Proc. 18th Ind. Sci. Congress, Nagpur, p. 303, (1931).

ice sheet must have spread over what is now the Himalayan chain of Sikkim at least as far as Lachi (28° 01′ : 88° 45′). The actual distance of expansion of this sheet would have been far greater, since the position now occupied by the Lachi series is the result of shortening due to folding and thrusting subsequent to the Gondwana period. There is an alternative explanation in the supposition that Hercynian, or embryonic Alpine movements may have initiated an elevation along the present Himalaya of sufficient magnitude to induce a local ice sheet to form adjacent to the main Gondwana ice sheet (in a manner comparable to the Alpine ice sheet in front of the larger Scandinavian sheet during Pleistocene times). Since, however, proved Gondwana rocks occur south of Darjeeling, now only some 70 miles away from Lachi, it is simpler to associate the whole series with one common cause, and assume the extension of the Gondwana ice sheet as far as what is now Tibet. The significance of this is that the northern edge of Peninsular India at that time must have been north of Lachi, and therefore that the whole of the Sikkim Himalaya belonged then properly to Peninsular India.

The glacial beds of Lachi in northern Sikkim overlie the Mount Everest limestone, which presumably was marine. They are also themselves overlain by the marine Tso Lhamo beds. It is evident that while most of Peninsular India remained almost continuously part of the Gondwana continent from the Carboniferous up to the Mesozoic era, its northern edge, such as in Sikkim, showed fluctuations between marine and continental conditions. The occurrence of marine *Productus* limestones in very close association with the Talchirs and continental Barakars of the Umaria coalfield (23° 30′ : 80° 48′) may be cited as an indication that even in Peninsular India there were local marine invasions. Such invasions do not vitiate the palæogeographic importance of the glacial beds, wherever they are found.

Metamorphics.

The nature of the Metamorphics in the Himalaya is well summarised on page 291 in the second edition of *A Sketch of the Geography and Geology of the Himalaya Mountains and Tibet*, from which the following passages may be quoted :—

'Thus we may regard the crystalline belt as composed of three elements, *viz.*, intrusive granite, metamorphic schists due probably to the action of the granite on the rocks into which it has been intruded and which it has partially absorbed; and, lastly, a series of old gneisses, schists, granulites and crystalline limestones, of which the advanced stage of metamorphism cannot be attributed merely to the Himalayan granite. These latter rocks, in fact, bear a marked resemblance to certain Peninsular types which are found in Madras, Burma, Ceylon, the Central Provinces ...... and Rajputana, and which are referred to the Archæan.......

Thus it is difficult to escape the conclusion that the axis of the Himalayan chain and of the associated ranges to the west is in part made up of true representatives of the oldest known group of rocks, and that these are merely the northerly extension of the similar rocks of the Indian Peninsula.

Proved pre-Cambrian sediments and metamorphics, as determined by their position relative to known Cambrian sediments, are found only in Kashmir, as Mr. Wadia's Salkhala series. Wadia and West consider, however, that the Jutoghs of the Simla Hills are equivalent to the Salkhalas, and the lithological comparisons mentioned in the above quotation suggest the strong probability that pre-Cambrian metamorphics occur further east. The difficulty of identification lies in the fact that post-Archæan granites, intruded under regional stress, may have converted Palæozoic and even later sediments into metamorphics resembling those of the Archæan. This has, of course, been realised, and is suggested in the quotation given above, but it is a possibility which has not, perhaps, been given the emphasis it deserves. In Scandinavia, Bohemia and the Alps there are strong grounds for assuming the regional extension of Palæozoic crystalline schists.

Aravalli strikes.

The Aravalli strikes found locally in rock structures in the Garhwal Himalaya also suggest a northward extension of Peninsular rocks into the Himalaya.[1] These rocks have been subsequently involved in the Tertiary movements, without, it is believed, the original structures having been rotated by the later movements so as to lose their former orientation. Geodetic work by the Survey of India has shown a region of high density continuing from Rajputana into the Himalaya near Dehra Dun. Lt.-Col. Glennie has consequently suggested that there may have been a buckling up of the Gangetic trough near Dehra Dun along a rejuvenated line of weakness continuing from the Aravalli range.[2] If this buckling originated only after the Gangetic trough had formed, it is clearly very recent, and would have no connection with the pre-Krol N.E.-S.W. structures found in the Himalaya. Some indication of recent activity along Aravalli directions is afforded by the present disposition of the Blaini-Krol-Tal

[1] *Rec. Geol. Surv. Ind.*, LXVI, p. 467, (1933).
[2] *Professional Paper No. 27*, Survey of India, pp. 18, 27, (1932).

sequence into three tectonic basins (west of the Tons river, between the Jumna and Ganges rivers, and east of the Ganges) which may also be due to rejuvenation in a N.E.-S.W. direction. It is difficult, however, to differentiate cause and effect, to decide to what extent rejuvenation along the Aravalli strike has been operative in contradistinction to the possible persistence of an incompletely base-levelled range projecting into the Himalaya. This question can only be decided after the distribution of rock facies in the Himalaya is better known. Factors such as the distribution of conglomerates in relation to a possible persistent N.E.-S.W. ridge, the occurrence of marine rocks such as the Krol limestone, and the dying out of the Dagshais and Subathus to the south-east, will all have a bearing on the problem[1].

(*b*) *As indicated by Palaeoclimates.*[2]

The existence of rocks of Peninsular type within the Himalaya may also be considered in the light of indications afforded as to the nature of palæoclimates. The following sequence of climatic events can be traced in Peninsular India. Dr. Fox and the writer maintain that the rocks of the Vindhyan system, in particular the series overlying the Semris, were deposited in a generally arid environment.[3] A correlation has been suggested between some of the Vindhyan rocks and those of the Cambrian sequence in the Salt Range. Gee has established the continuity of sequence from the Neobolus shales up to the Salt Pseudomorph beds, and the Cambrian age of the latter.[4] The existence of arid conditions during the Cambrian is therefore certain. The Talchir tillite, of Upper Carboniferous age, proves that glacial conditions prevailed at that time. By Panchet (Trias) times, however, in the Gondwana epoch, the climate had again become arid.[5]

With regard to the climatic sequence in the Himalaya, the grounds are less sure partly because metamorphism may have obscured diagnostic characters. The Chandragiri limestones of Nepal, of probable Ordovician age, afford no indications as to climate. The rocks imme-

[1] For a discussion of this problem as it relates to Peninsular India, *see* Fermor, *Rec. Geol. Surv. Ind.*, LXII, p. 391, (1930).

[2] The substance of this section has appeared in Abstracts of Papers, Section of Geology, 22nd Annual Meeting of the Indian Science Congress, 1935.

[3] *Mem. Geol. Surv. Ind.*, LXII, p. 223, (1933).

[4] *Rec. Geol. Surv. Ind.*, LXVIII, p. 115, (1934).

[5] *Mem. Geol. Surv. Ind.*, LVIII, p. 104, (1931). Wadia, Geology of India, p. 127, 1926).

diately underlying the Chandragiri limestones nevertheless show a striking resemblance to the Semri series of the Vindhyan system in colour and nature of sedimentation. In the more westerly Himalaya, of the United Provinces, the Mandhali and Nagthat stages of the pre-Blaini Jaunsar series are characterised by frequent purple and green colours, by ripple-marked quartzites and by conglomerates and boulder beds. The conditions of deposition of these beds have not been properly elucidated. A closely adjacent upland or mountain terrain is implied, however, to supply the coarse clastics, and the conditions were probably in the main fluviatile and continental, in contrast to the generally marine deposition of the fossiliferous Palæozoic sequence of the Spiti area a short distance to the north. The origin of all the boulder beds is not known. The question is rendered difficult by the obscure relationships of the Mandhali and Nagthat stages, in a manner which appears to be comparable to that of the composite Tanols in Kashmir.[1]

The Blaini boulder bed is regarded as glacial and as equivalent to the Talchir boulder bed of the Peninsula.

A short distance above the Blaini, and separated from it only by the Infra-Krol shales and slates, is the local Krol sandstone of the Solon area, in which wind-blown sands are a characteristic feature.[2] These winds could have been either hot or cold.

Gypsum, in one place probably with anhydrite also, has been found in the Krol limestone.[3] The inversion temperature of gypsum into anhydrite is 63·5° C. (146° F.) in pure water, and 36° C. (97° F.) in a saturated solution of sodium chloride[4]. It may be possible therefore to postulate the existence of warm conditions, presumably with a considerable concentration of salts (since the temperature of sea water seldom rises above 35° C. or 95° F., which is far below the inversion temperature of gypsum into anhydrite in pure water) during the time of deposition of the Krol limestones. Dessication does not necessarily imply the existence of uniformly warm conditions. The winter temperature of the brackish Caspian sea and the saline gulf of Karaboghaz is about 0° C. The summer temperature

[1] The whole question of the sequence of the pre-Blaini rocks is one of great difficulty. From the point of view of this paper it is sufficient to accept that the rocks mentioned are pre-Blaini and very probably Palæozoic.

[2] *Rec. Geol. Surv. Ind.*, LXII, p. 168, (1929).

[3] *Rec. Geol. Surv. Ind.*, LXVII, p. 450, (1934).

[4] J. W. Mellor, A Comprehensive Treatise on Inorganic and Theoretical Chemistry, Vol. III, p. 770, (1923).

is about 27° C. (80° F.).[1] It is unwise at present to press the occurrence of gypsum too far in this connection since the origin of the calcium sulphate in the Krol limestones is not definitely known. The gypsum may in places have been a replacement mineral though the evidence at Ridana suggested there its primary origin. Further, the inversion of gypsum to anhydrite may be due, as Dr. Fox has suggested to me in conversation, to stress: anhydrite has the smaller molecular volume and may be the stress form of calcium sulphate. Hayden has described the gypsification of Carboniferous limestones in the Spiti area, showing that the gypsum there arose out of the action of sulphurous waters on limestone.[2]

Following upon the marine Krol series are the Tal rocks.[3] The upper Tal stage is represented by from 2,000 to 4,000 feet of white and purple quartzites, current-bedded and ripple-marked, and of intercalated sun-cracked muds. This stage was clearly laid down under fluvio-deltaic conditions. Proximity to the sea is indicated by the occurrence in Tehri Garhwal and Garhwal of a sandy limestone at the top of the stage full of broken lamellibranchs and brachiopods. The combined Krol-Tal sequence ranges with fair certainty from late Palaeozoic to the Mesozoic.

The sequence of events in the Peninsular Himalaya is certainly complicated by marine invasions. But the prevalence of fluviatile and continental conditions, and certain qualitative indications in the marine rocks, seem sufficient to suggest that both Peninsular India and the Peninsular Himalaya underwent the same broad climatic changes.

It is understandable that these climatic changes would have little effect on the faunal population of the open sea, including the Tethys for the greater part of its history. Climatic influence would be more strongly felt, however, in the region immediately to the south of the Tethys where the rocks, even though water-deposited, must have been laid down in areas frequently land-locked and shut off from the open ocean. Comparison may be made with the Germanic facies of the Trias bordering the Alpine geosynclinal facies.

[1] January and July Temperature Charts, as in the Oxford Advanced Atlas, p. 16, (1931).

[2] *Mem. Geol. Surv. Ind.*, XXXVI, Pt. 1, p. 41, (1904). Fieldwork during the 1935 season has shown that gypsum found in the Upper Krol limestone of the Dehra Dun district is replacive. At Sera (30°18′: 78°14′) replacive gypsum is found within 500 yards of a sulphur spring.

[3] *Rec. Geol. Surv. Ind.*, LXVII, p. 384, (1934).

The almost complete absence of fossils from the rocks of the Peninsular Himalaya is a most significant feature, and may perhaps be explained by the somewhat stringent conditions which prevailed. It may be remarked, however, that in other areas which must have been subject to equally stringent conditions (Old Red Sandstone of Britain, Permo-Trias of Britain and Germany, Panchet of India) the faunas of the time survived in sufficient numbers to permit the age of the rocks being determined. This absence of fossils was discussed by Pilgrim and West,[1] although not explained by them, and has again been recently discussed by West.[2] A satisfactory explanation has yet to be found.

Conclusions.

The above considerations suggest the strong unity which must have existed between what are now the Himalaya and the Indian Peninsula, and add emphasis to the conclusions previously given by Hayden and Burrard.[3] The striking bands of Siwalik rocks and Indo-Gangetic alluvium, which run from the Punjab into Assam, divide off the Himalaya from Peninsular India. The rocks of the Himalaya have, moreover, been caught up in the later Tertiary folding and are in positions unlike what is known of the outcrops of their believed equivalents in the Peninsula. In spite of this present divorce of the Himalaya from the Peninsula, much of the Himalaya should be considered as made up of the foreland to the Tethys sea, and of its continental shelf. It may be suggested that emphasis should be made on the division of the Himalaya into two main types :—

(1) Tethys Himalaya ; Spiti, Tibet, etc.
(2) Peninsular Himalaya ; most of the outer Himalaya, and, possibly at one time, all of Sikkim.

2. Darjeeling Gneiss and Dalings.

Vertical distribution.

As has long been known in Sikkim, and has now been found to obtain in Nepal, the Darjeeling gneiss overlies the Daling series. This fact is indisputable. Two explanations suggest themselves. The first is that the Darjeeling gneiss and the Dalings are two distinct series, separated

[1] *Mem. Geol. Surv. Ind.*, LIII, p. 133, (1928).
[2] *Current Science*, III, p. 289, (1935).
[3] *A Sketch of the Geography and Geology of the Himalaya Mountains and Tibet*, 2nd Edn., p. 296, (1934).

by a thrust plane. This view is favoured by Dyhrenfurth and to some extent by Wager. In Wager's section, a thrust plane is marked between the two series,[1] but in the text he states that intrusion of granite into the Dalings near Gangtok has caused the Dalings to resemble Darjeeling gneiss, remarking that ' this may one day afford a clue to the origin of the latter ' [2]. The second explanation is that the granite under regional stress has invaded the upper part of a great sedimentary series converting it, where invaded, into a series of mixed ortho- and paragneisses. This view was arrived at independently by Dr. A. M. Heron and myself. Dr. Fermor had previously adopted a somewhat similar explanation, namely that the strips of para-schists in the gneiss of north-eastern Sikkim represent portions of the Daling series that have been infolded within the ortho-gneisses and rendered at the same time thoroughly crystalline. Dr. Fermor noticed that the slates of the Daling series become more crystalline as the gneiss boundary is approached.[3]

The features observed in connection with the Darjeeling gneiss and the Dalings may be summarised as follows :—

(1) It is difficult to trace an exact boundary between the Dalings and the Darjeeling gneiss. The Dalings become more coarsely chloritic and schistose upwards towards the schists and gneisses of the Darjeeling gneiss group. This transition has been noticed north-west and east of Katmandu in sheet 72 E, south of Dhankuta in sheet 72 N, along the Arun and Khabeli valleys in sheet 72 M, and along the Teesta valley in sheet 78 A. The transitional zone between the Daling phyllites and the gneiss complex is too wide to permit of any exact boundary or thrust plane being drawn between them on a large scale map. This difficulty of drawing a sharp boundary was experienced by Mallet over most of the area he mapped.[4]

(2) The transitional chlorite-sericite-biotite phyllites and schistose phyllites often contain small garnets. Some of these rocks may be regarded as retrogressive, but the cause of the retrogression is not necessarily due to shear. Hydrothermal action may have been locally operative.

[1] ' Everest 1933 ', p. 327.
[2] *Ibid.*, p. 320.
[3] *Rec. Geol. Surv. Ind.*, XLII, p. 92, (1912).
[4] *Mem. Geol. Surv. Ind.*, XI, pp. 41-42, (1874).

(3) There is evidence, which can only be proved by detailed mapping, that a calcareous band along the Arun valley moves from what in one place must be regarded as Dalings to what further north must be mapped as gneiss.

(4) In Scotland there has been worked out by Barrow, Tilley and others the well known progressive sequence of metamorphic zones :—chlorite zone; biotite zone; almandine zone; staurolite and kyanite zones; sillimanite zone.[1] In Nepal and Sikkim it is possible that detailed mapping may establish a somewhat similar sequence. From the cursory examination that I was able to make, there is the following suggested sequence with regard to the pelitic rocks :—

(*Top*)

Kyanite-schists Garnet-biotite-schists	Darjeeling gneiss.
Porphyroblastic chlorite-sericite-phyllites, often with garnet	transitional.
Chlorite-sericite-phyllites Slates and phyllites	Dalings.

(*Bottom*)

It seems possible, therefore, that the sequence may be regarded as illustrating a true progressive increase in metamorphism upwards.[2] I do not think that there are sufficient grounds for postulating a thrust plane between the Dalings and Darjeeling gneiss as was maintained by Dyhrenfurth, and is shown in the section on page 327 of " Everest 1933 ". Locally there may be faults and even thrusts, such as the one mapped by Mallet north of Darjeeling, but the general disposition seems to be one of gradation. In view of these facts, it is possible as previously stated that the terms Dalings and Darjeeling gneiss may apply respectively to the lower and upper portions of a great sedimentary succession, the upper part of which has been injected and metamorphosed by granite magma under

[1] Harker, ' Metamorphism ', pp. 208-229, (1932).

[2] Professor F. E. Suess has suggested that the sequence of metamorphic zones in the Dalradians of Scotland, with increase in metamorphism upwards, may be due to retrogressive effects which have acted strongest towards the base of the succession. But whether the present disposition is due solely, as the British geologists believe, to progressive metamorphism or to an initial progressive metamorphism modified later by retrogressive effects, it seems clear that the rocks of the various grades now seen belong to the one Dalradian series. *Sitz. d. Math.-Naturwiss. Kl.*, 5.7.34, (Akad. Anzeiger), Akad. d. Wiss., Wien.

stress. The colours marked on the map (*see* Plate 8), would in this case represent metamorphic facies rather than definite stratigraphical stages, or two distinct series separated by a thrust plane. In general, *lit par lit* intrusion by its very nature would tend to keep more or less to stratigraphic horizons, but this is evidently not everywhere so. The penetration of magma in the upper part of such a succession is certainly a remarkable feature. One may perhaps regard such an extensive magma migration as having taken the place of translation of solid rock across great thrust planes, though the factors operative in the two cases would be different.[1]

Horizontal distribution.

As regards the continuation of the Dalings and Darjeeling gneiss, to the north-west, I have little doubt that both are found westwards as far as Katmandu. I would suggest also that the granites of Dwarahat, Dudatoli and Lansdowne in Garhwal may be equivalent to the igneous portion of the Darjeeling gneiss. In these cases also there appears to be the same intimate connection between intrusion of granite and metamorphism, and the same gradation from phyllites to schists, as was described by Middlemiss in 1887.[2] A good example may be seen on the path from Ranikhet to Dwarahat (*see* page 133).

With regard to the main Himalayan range, there is a strong similarity between the quartzitic and calcareous granulites of the Alaknanda valley and Sikkim. The Nepal ranges are not known, but specimens collected by Wager of the Lower Everest limestone resemble the calciphyres and calc-granulites of Garhwal and Sikkim. Since the geological strike of these bedded granulites (so well seen also on Kedarnath from the south-west, Trisul from the west and on Nanda Devi)[3] coincides in general with the geographical alignment of the Great Himalayan Range, it is a reasonable conclusion that this range is built throughout a distance of some 600 miles (1,000 kilometres) of a great series of granulites with intrusive ortho-gneisses and granites.

[1] After this account had gone to the press there has appeared a paper by S. K. Ray on the Gneissic Complex of the Darjeeling District, which confirms the conclusions given above. *Quart. Journ. Geol. Min. Metal. Soc. Ind.*, VII, (1935). On page 44 he states :—

'It has, thus, been shown that the gneisses and schists of the Darjeeling area are the products of regional metamorphism of an argillaceous sedimentary formation and that the whole area, particularly the sillimanite gneiss near Darjeeling, has been permeated with late magmatic emanations in the form of pegmatites, aplites, pneumatolysers and other late-stage fluids.'

[2] *Rec. Geol. Surv. Ind.*, XX, p. 137, (1887).

[3] See, for instance, the photograph opposite page 28 of *Himalayan Journal*, Vol. V, (1933).

The connection between the N.W.-S.E. extension of the Darjeeling gneiss complex in the lesser Himalaya and the similar extension of the rocks comprising the Great Himalayan range is at present hardly known. In Sikkim, the Darjeeling gneiss joins up with the rocks of the Kanchenjunga and Pauhunri massifs, but the precise differences between the gneissic complexes of the two areas in Sikkim which must exist to allow of such contrasts in topography have not been discovered. According to Wager, the contrast may be due chiefly to differential isostatic uplift. In Garhwal there is probably a thrust separating the granulites of the main range from the apparently underlying Garhwal limestone which occurs to the south.

Significance of the Middle Siwaliks.

Finally, mention may be made of the Middle Siwalik sand-rock which forms such a characteristic feature of the Siwalik outcrop from the Punjab at least as far east as about longitude 86°. This sand-rock on superficial examination might sometimes almost be taken for granite, so full is it often of feldspar and mica. Its occurrence in great cliffs without visible bedding, such as near Dhukwabas (27° 19′ : 85° 00′), tends also to belie its sedimentary origin. Such a rock must have been laid down as the result of the denudation of a granitic or metamorphic terrain.[1] The provenance of this was possibly the equivalent of the Darjeeling gneiss complex in the western Himalaya. There may prove to be a reciprocal relationship between greater erosion of this complex in the west and a more extensive development of the Middle Siwaliks.

3. The Sikkim granite.

Where I saw this granite in northern Sikkim it was always unfoliated, and characteristically transgressive. It is the youngest of the intrusives that were seen. Heron[2] noticed in the Everest region that the schorl granite—

'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 sill is specially characteristic, namely concordance with the foliation of the rocks into which they are intruded.'

While Heron was impressed by the concordant sill-habit of this granite, he also remarks that it is later in age than the gneiss and

[1] Wadia, 'Geology of India', p. 237, (1926).
[2] *Rec. Geol. Surv. Ind.*, LIV, p. 221, (1922).

metamorphics. In Sikkim, the transgressive habit is the more striking, especially at the northern end of the Sebo Chu valley (*see* Plate 6). In the cliffs west of the terminal moraine of the Khonpuck glacier, the granite occurs in a network of clean-cut veins and dykes which evidently bear some relation to the regional jointing. The conclusion from these observations is that this fine-grained white granite (described on page 150) is later than the ortho-gneisses it cuts. The unfoliated granite of Sikkim and that of Chumbi are regarded by Hayden as equivalent, and doubtless also the schorl granite of Everest belongs to the same suite. Since the Chumbi granite intrudes Jurassic beds, both it and the related granites of Everest and Sikkim are probably Tertiary in age. The question remains as to whether or not the ortho-gneisses cut by the Sikkim granite are also Tertiary. Wager shows the lateral passage from the Chumbi granite into Darjeeling gneiss near Yatung[1]. Dyhrenfurth believes the augen-gneiss of Kanchenjunga to be younger than his Mesozoic Dodang series[2]. Hayden grouped the foliated biotite-granite and the muscovite-schorl-granite of the Himalayan crystalline zone together, and contrasts them with the markedly different hornblende-granite of Kyi Chu[3]. These views imply, therefore, that a number of granites in Sikkim and Tibet are closely related, and probably of Tertiary age. All that can be stated at present is that the white, fine-grained, tourmaline-granite of northern Sikkim appears to be the youngest of the intrusives present, and, by analogy with the Chumbi granite, is probably Tertiary, while the intrusives it cuts may be either Tertiary or older.

Wager points out the difficulty in distinguishing between the older granite-gneisses and the younger, probably Tertiary granite-gneisses. He states, however, that the former differ in being garnet-bearing, and in being associated with amphibolite bands, highly metamorphosed limestones, quartzites and shales.[4] Garnet may be seen in the pegmatites both of the Saraswati-Alaknanda valley in Garhwal (44/66) and in the Kabeli valley of Nepal. Specimen 44/66 is of a contact between garnet-tourmaline-pegmatite and biotite-granulite. It occurs in association with the more common pegmatites which do not contain garnet, and both garnet-bearing and non-

[1] 'Everest 1933', p. 327.
[2] 'Himalaya: Unsere Expedition', p. 303.
[3] *Mem. Geol. Surv. Ind.*, XXXVI, Pt. 2, p. 59, (1907).
[4] *Loc. cit.*, p. 320.

garnet pegmatites are fairly certainly derived from the same magma that gave rise to the large granite and gneiss intrusions of northern Garhwal. It is these intrusions which many believe are Tertiary in age. Further, both types of pegmatite occur intrusive into the metamorphosed granulite group of Garhwal. The criterion of the presence or absence of garnet seems of uncertain value if it be used to characterise the older gneisses and if at the same time it occurs in pegmatites related to the younger transgressive granites.

EXPLANATION OF PLATES.

PLATE 3. Overfold in Triassic limestones, Matayan, Dras valley, Kashmir. Direction of view E.S.E.

PLATE 4. Biafo glacier and the main Karakoram range, Baltistan. View towards 345° from the spur above camp 12,800, showing interbedded marbles (pale bands) and biotite schists, etc. The highest peaks (22-24,000 feet) are probably of granite.

PLATE 5, FIG. 1. Current-bedded granulites, mile 170½ on the Hardwar-Badrinath pilgrim track, just below Pandukeswar, Garhwal.

FIG. 2. Current-bedded granulites, mile 168 on the Hardwar-Badrinath pilgrim track, north of Vishnuprayag, Garhwal.

PLATE 6. Wall of peaks enclosing upper Sebo Chu valley, north-east Sikkim. Flat fold in ortho- and para-gneisses ; intrusive granite seen cutting across the gneisses below both the main peaks. The peak on the left or west side is probably Survey of India peak No. 109, marked as ' Round Snow, 22,960 ' in the older maps. View taken from the corrie 16,500 camp in an E.N.E. direction.

PLATE 7, FIG. 1. Pauhunri (23,180 feet) massif and satellite hill of 21,000 feet ; Sikkim-Tibet frontier. Position of fossiliferous rocks shown by arrows. Teesta glacier on the right. Telephoto view from the flats east of Kerang, at about 18,000 feet, towards the south-east.

FIG. 2. Tso-Lhamo beds, seen from the south on Lachi hill, at about 17,600 feet, north-east Sikkim. Position of fossiliferous beds shown by arrows. Northern end of Tso Lhamo visible. Moraine-covered slopes of the Sikkim-Tibet frontier seen in background. Early winter snow.

PLATE 8. Sketch map of the Geology of eastern Nepal and Sikkim, scale 1 : 1,000,000. Compiled from the work of numerous authors. Considerable portions of the boundaries in Nepal have been interpolated, and do not pretend to great accuracy. The general geological aspect is believed, however, to be reasonably shown.

J. B. Auden, Photo. *G. S. I., Calcutta.*

OVERFOLD IN TRIASSIC LIMESTONES. MATAYAN, DRAS VALLEY, KASHMIR.

J. B. Auden, Photo. *G. S. I., Calcutta.*

BIAFO GLACIER AND MAIN KARAKORAM RANGE FROM SPUR ABOVE CAMP 12,800. INTERBEDDED MARBLES (PALE BANDS) AND BIOTITE SCHISTS.

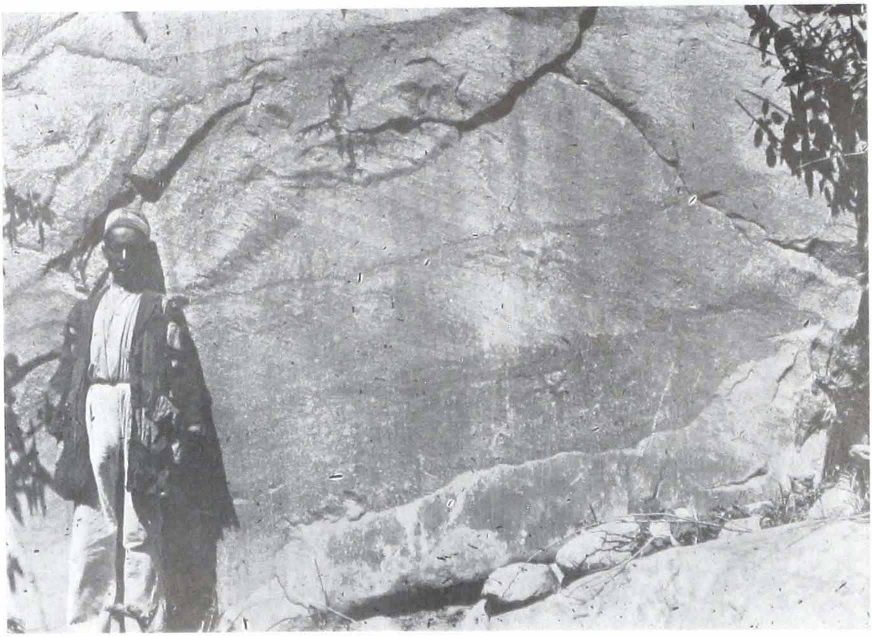
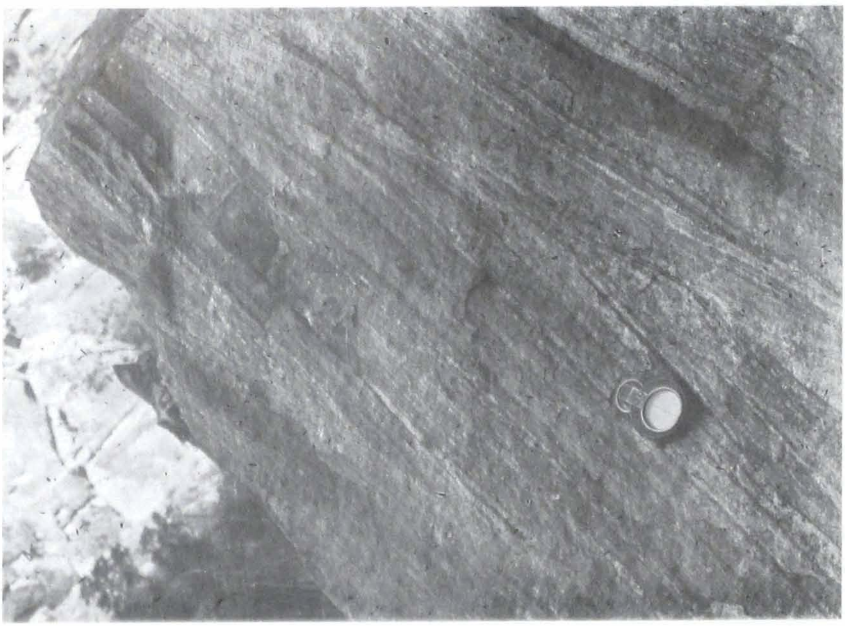
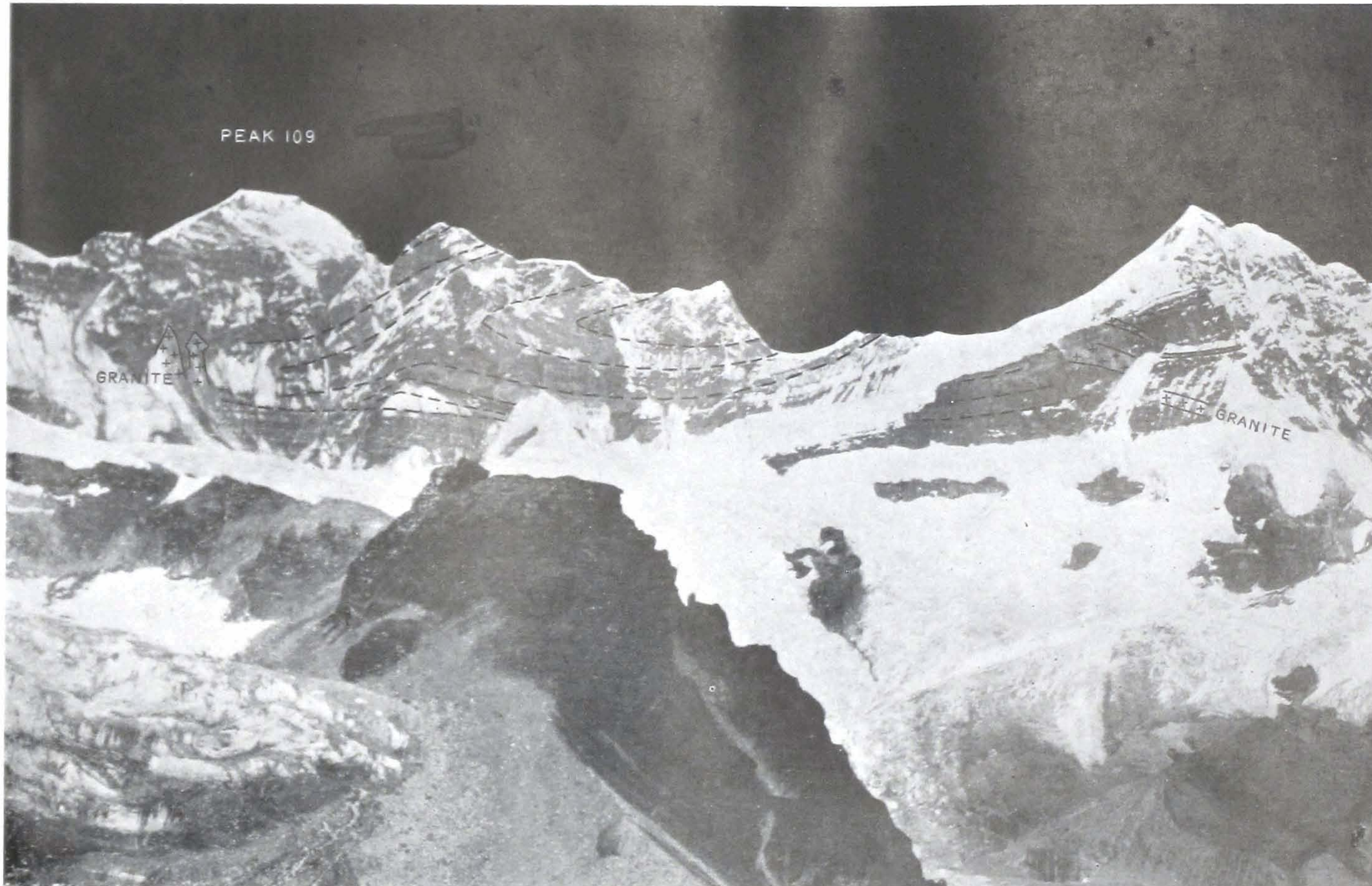


FIG. 1. CURRENT-BEDDED GRANULITES, MILE 170½, HARDWAR-BADRINATH PILGRIM TRACK, JUST BELOW PANDUKESWAR, GARHWAL.



J. B. Auden, Photos. *G. S. I., Calcutta.*

FIG. 2. CURRENT-BEDDED GRANULITES, MILE 168, HARDWAR-BADRINATH PILGRIM TRACK, NORTH OF VISHNUPRAYAG, GARHWAL.



J. B. Auden, Photo. *G. S. I., Calcutta.*

WALL OF PEAKS ENCLOSING UPPER SEBO CHU VALLEY, SHOWING FLAT FOLD IN ORTHO- AND PARA-GNEISSES, NORTH-EAST SIKKIM.

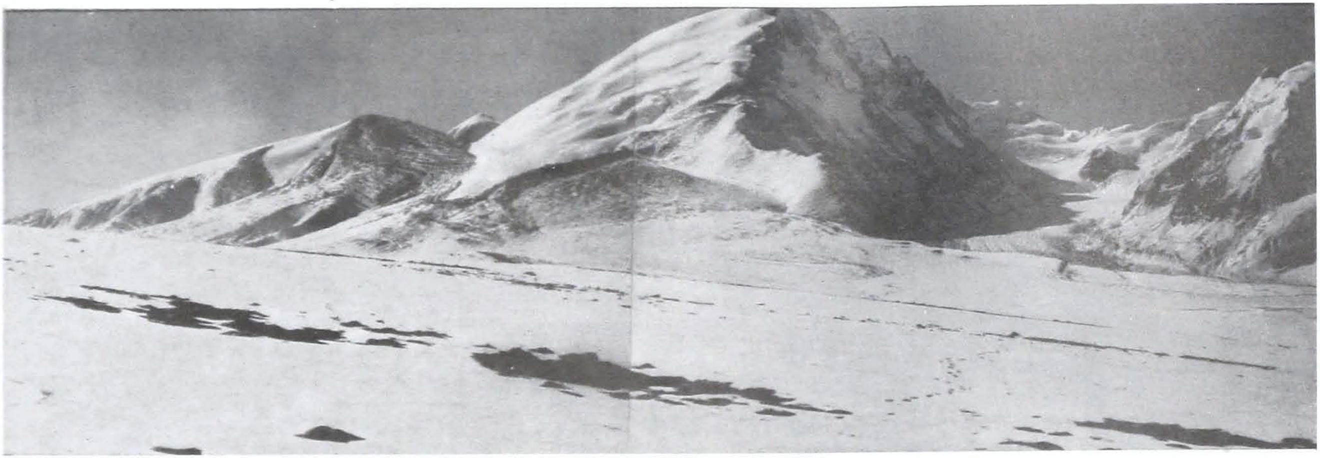
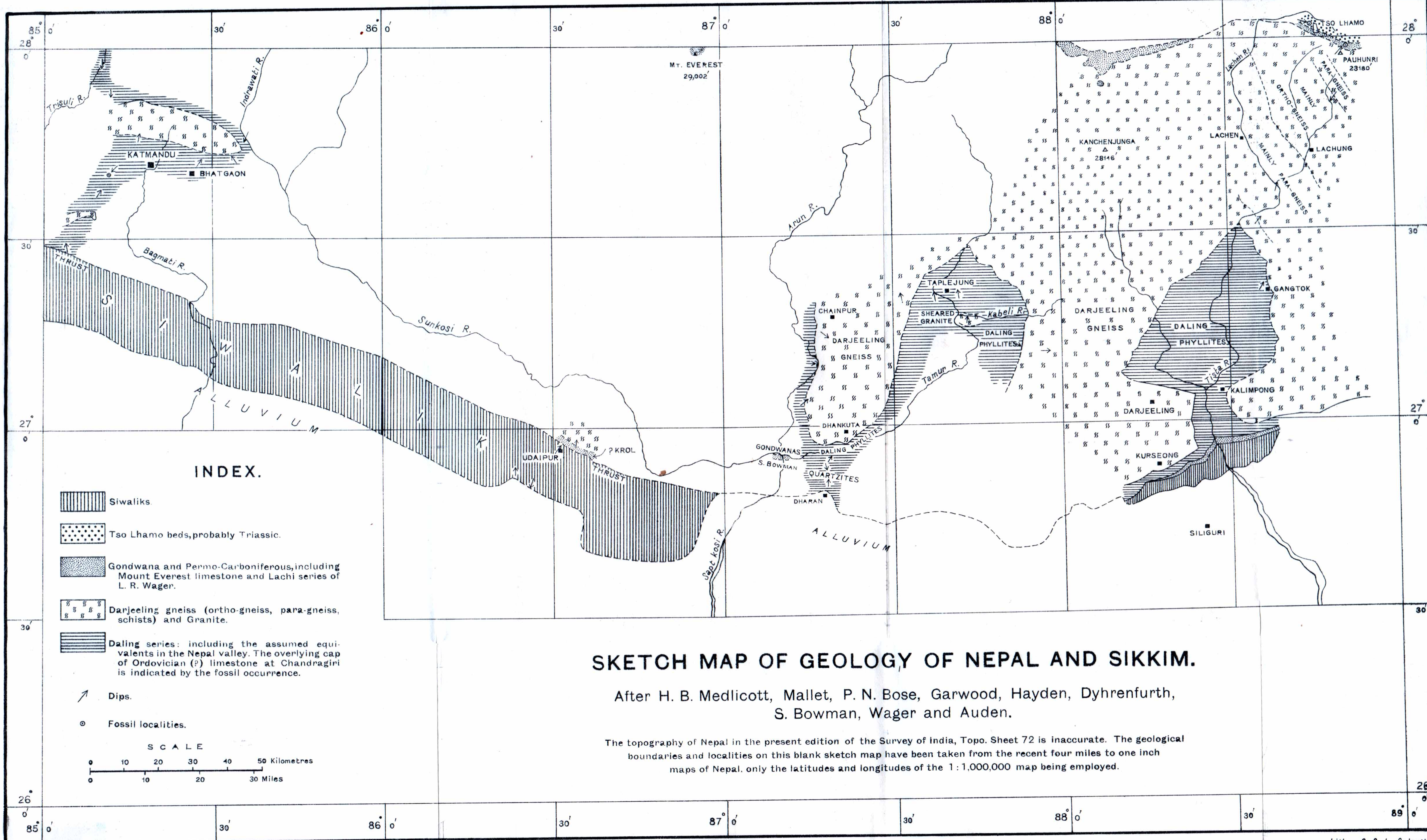


FIG. 1. PAUHUNRI 23,180 AND SATELLITE HILL 21,000. POSITION OF FOSSILIFEROUS ROCKS SHOWN BY ARROWS. SIKKIM-TIBET FRONTIER.

J. B. Auden, Photos. *G. S. I., Calcutta.*

FIG. 2. TSO LHAMO BEDS, SEEN FROM THE SOUTH ON LACHI HILL, SIKKIM.



SKETCH MAP OF GEOLOGY OF NEPAL AND SIKKIM.

After H. B. Medlicott, Mallet, P. N. Bose, Garwood, Hayden, Dyhrenfurth, S. Bowman, Wager and Auden.

The topography of Nepal in the present edition of the Survey of India, Topo. Sheet 72 is inaccurate. The geological boundaries and localities on this blank sketch map have been taken from the recent four miles to one inch maps of Nepal, only the latitudes and longitudes of the 1 : 1,000,000 map being employed.

A. K. Chandra, Lith.

Litho., G. S. I., Calcutta.