THE STRUCTURE OF THE HIMALAYA IN GARHWAL. BY J. B. AUDEN, M. A., F. G. S., *Geologist, Geological Survey of India.* (With Plates 35 to 37.)

CONTENTS.

I.—INTRODUCTION.

The object of this paper is to summarise my present views on the structure of the outer Himalaya between the Jumna River and Lansdowne, as well as to introduce a preliminary interpretation of a profile across the Garhwal Himalaya from the Plains to the Main Himalayan Range. I shall not discuss lithology, or the stratigraphical relationships of the various rock groups. That will be reserved for a Memoir which it is hoped to write shortly.

At intervals during the last eight years it has been my duty to make a detailed survey of the lower Himalaya, working south-eastwards from Lat. 31°N. : Long. 77°E. to Lat. 30°N. : Long.

78° 30′ E. The region with which this paper is chiefly concerned lies east of Long. 78°E. and is about 1,500 square miles in area. In addition traverses have been made to the snowy ranges up the Alaknanda and Bhagirathi branches of the Ganges river. The whole region is included within Survey of India map No. 53, on the scale of 1 : 1,000,000; see Plate 36.

1. Historical.

In 1864 H. B. Medlicott published the first connected account of the geology of the lower Himalaya[1]. The area he described is about 7,000 sq. miles and lies for the most part west of the Tons river, centering around Simla. Important though this memoir is, it has little direct bearing on the region east of Long. 78°. Moreover, Medlicott's work has already been discussed by G. E. Pilgrim and W. D. West[2] and later to some extent by myself[3], so that it can be omitted from the discussion which follows.

Between 1885 and 1890 C. S. Middlemiss carried out detailed surveys in three areas of the Kumaon Division :—

(1) along the outer Himalaya between the Ganges river and Gungti hill (29° 45′ : 78° 55′)[4];

(2) around Dudatoli mountain (30° 03′ : 79° 12′)[5];

(3) the Siwalik ranges from the Ganges to the Nepalese frontier[6].

It is with the first area that we are most directly concerned, since it overlaps that in which I have worked and since it afforded indications of enormous tectonic movements in the Himalaya.

In 1891 C. L. Griesbach published a Memoir on his survey within, and north of, the Main Himalayan Range[7].

Between 1883 and 1888 R. D. Oldham published accounts of his mapping in the Chakrata Tahsil of Dehra Dun district and in regions to the west of the Tons river[8]. He was unfortunate in working on an isolated area of exceptional geological complexity,

[1] *Mem. Geol. Surv. Ind.*, III, (1864).
[2] *Op. cit.*, LIII, (1928).
[3] *Rec. Geol. Surv. Ind.*, LXVII, p. 357, (1934).
[4] *Rec. Geol. Surv. Ind.*, XX, p. 33, (1887).
[5] *Op. cit.*, p. 134, (1887).
[6] *Mem. Geol. Surv. Ind.*, XXIV, (1890).
[7] *Op. cit.*, XXIII, (1891).
[8] *Rec. Geol. Surv. Ind.*, XVI, p. 193, (1883); XXI, p. 130, (1888).

the southern part of which even now, after a fuller survey of the surrounding regions, has not yielded any satisfactory solution of structure.

After an interval of forty years, detailed mapping was begun in the Simla area by Pilgrim and West, who demonstrated for the first time in that part of the Himalaya the existence of great overthrusts[1]. I was attached to the Himalayan party in 1928, and, working to the south-east from Subathu, have joined up with the area already mapped by Middlemiss south-east of the Ganges river. A paper of mine on the Geology of the Krol Belt was published in 1934 in which the portion of the outer Himalaya between longitudes 77° and 78° was described[2]. A further paper was published in 1935 describing traverses carried out in the Karakoram, Garhwal, eastern Nepal and Sikkim[3].

2. Topographical and Geological Zones in the Garhwal Himalaya.

Before describing the tectonics of the Garhwal Himalaya in greater detail, a brief mention may be made of the zones into which it can be divided. Topographically the following zones may be distinguished :—

1. Siwalik Range and Dun.

2(*a*). Outer lower Himalaya, with an intricate network of spurs and rivers.

(*b*). Inner lower Himalaya, with simpler topography.

3. Main Himalayan Range, with steep scarp slopes facing towards the Plains, and gentler dip slopes facing Tibet.

4. High peaks north of the Main Himalayan Range with irregular disposition.

The structural units do not fit into this topographical classification, since, in some parts at least, three structural units are superimposed one upon the other. The main tectonic divisions for the Garhwal Himalaya are as follows :—

(1) Autochthonous unit. The base of this unit is probably the Simla slate series, overlying which occur Nummulitics,

[1] *Mem. Geol. Surv. Ind.*, LIII, (1928).
[2] *Rec. Geol. Surv. Ind.*, LXVII, p. 357, (1934).
[3] *Op. cit.*, LXIX, p. 123, (1935).

Murrees and Siwaliks. Thrusts occur within this unit, but do not seem to be of premier magnitude. The most important thrust is that which has long been called the Main Boundary Fault. This Autochthonous unit appears to occur well within the Himalaya, some twenty miles at least from the Dun.

(2) The Krol Nappe, thrust upon the Autochthonous unit, and corresponding to the Krol Belt described in a previous paper of mine.

(3) The Garhwal Nappes, thrust upon the Krol Nappe. The main Garhwal Nappe may root in the Main Himalayan Range.

(4) The Main Himalayan Range, which appears to be made up partly of elements common to one of the Garhwal Nappes and partly of a distinct group of para-gneisses and schists.

(5) The granite zone to the north of the Main Himalayan Range, containing granites intrusive into the southern para-gneisses and schists.

(6) The Tethys zone of fossiliferous sediments. The relationship of this zone to the granites and para-gneisses is at present obscure. From the work of Hayden in Spiti it would appear that the gneissic granite, which may be Permian or Tertiary in age, has an intrusive contact with the Cambrian. The recent work of Professor Arnold Heim and Dr. Gansser may clear up this question.

The greater part of this paper will be devoted to a discussion of the Autochthonous, Krol and Garhwal units occurring in the outer lower Himalaya. Before examining the results of recent work, it is necessary to summarise the interpretation given by Middlemiss to the outer lower Himalaya south-east of the Ganges river.

II.—MIDDLEMISS, 1887.

In 1887 Middlemiss published his important paper on the Physical Geology of West British Garhwal[1]. This was followed

[1] *Rec. Geol. Surv. Ind.*, XX, p. 33, (1887).

by a memoir on the Siwalik rocks in 1890[1]. The earlier work appears to have been carried out within two seasons, and one is amazed at the extent of ground covered and the general accuracy of the mapping. The only complaint is that, in a region offering so many problems, Middlemiss should intentionally have omitted elucidation of all except the most pressing one. The succession as determined by him is given below :—

——	Sub-Himalayan (Siwalik).
Outer Formation . .	Nummulitic. Tal. Massive Limestone. Purple Slates. Volcanic Breccia.
Inner Formation . . .	Schistose series with intrusive gneissic granite.

Middlemiss found that the schistose series occurred in an outcrop enclosed by, and apparently overlying, rocks of the Outer Formation. Almost all his discussion is confined to this relationship. His argument is summarised below.

The sequence of the rocks of the Outer Formation is a normal one, and is established by the presence in it of two fossiliferous horizons, Nummulitic and Tal limestone, the Nummulitic being the youngest and on top. The disposition of the Inner Schistose series in relation to this normally lying Outer Formation is best given in his own words[2] :—

> '....at every point round the schistose area the Outer formations appear to dip towards and under the schistose series at steep angles (50°-60° generally); whilst the schistose series itself is disposed apparently in the form of an elongated quaquaversal synclinal upon the top of the Outer formations, and culminates in a capping of gneissose rock on the summit of Kalogarhi mountain.....
>
> In other words, the observer after a hasty examination is almost driven to the conclusion that there is an upper metamorphic series lying normally upon the comparatively unmetamorphosed zone of Outer formations (a counterpart of the opinion long held with regard to the strata of the Scotch Highlands)'.

Again, on page 36, after commenting on the rocks of the Outer Formation being in their natural order (which is not true over

[1] *Mem. Geol. Surv. Ind.*, XXIV, (1890).
[2] *Rec. Geol. Surv. Ind.*, XX, p. 34, (1887).

part of the area) and dipping inwards towards the schistose rocks, he remarks :—

'One seems almost driven to conclude that if a boring were sunk through the centre of the schistose area, we should inevitably strike the Tal beds below'.

Middlemiss then attempts to prove that this conclusion would be wrong, claiming that the facts

'not only render the above interpretation unacceptable, but emphatically negative it'.

Firstly, he states on page 37 that if the Tal beds in reality continue below the schistose series, it follows that the Nummulitics, where present, must do the same :—

'that is to say, a soft, shaly, tertiary rock, not only must lie as a foundation on which the schists are piled, but also must be beneath them in direct contact'.

Such a case of selective metamorphism is ruled out as impossible, from which Middlemiss concluded that the schistose series must be older than the Nummulitics.

Secondly, having established that the schistose rocks are older than the Nummulitics, he argues that they must have been moved by reversed faulting against the Nummulitics. The argument on page 38 is a little involved, but the conclusion is that a combination of the 'sigma-flexure' with a reversed thrust plane is sufficient to explain the relative positions of the Outer and Inner Formations.

This same argument is repeated in *Memoirs, Geological Survey of India,* 24, pp. 73-77, (1890), namely that the Nummulitics must be younger than the schistose series, and that the rocks of the Outer Formation are separated from the overlying schistose series by a reversed fault. On page 74 of this memoir the fault is stated to dip in one place at about 25° northwards, as is also shown in Section VI.

It is necessary, therefore, on this thesis, to imagine a reversed fault, of ring shape, everywhere dipping inwards centripetally below the schistose series.

The argument of Middlemiss is weak, because it does not succeed in proving, as he imagined, that the schistose series cannot completely overlie the Nummulitics and Tals. It only indicates that the schistose series are older than the Nummulitics and that their position with respect to the Nummulitics cannot be a normal stratigraphical one. It suggests nothing about the nature of the dislocation which has caused the Nummulitics and schistose series to be brought together by an abnormal contact. Middlemiss chose to assume a ring-shaped reversed fault and therefore an essentially autochthonous disposition, but did not consider the possibility of a great overthrust bringing the schists and slates to overlie completely the Nummulitics and Tals. He refers to the Scottish Highlands (pp. 33, 34), and specifically mentions the solution to the problem there by Peach and Horne, but considered that the Garhwal area examined on its own merits did not warrant a similar explanation. I hope to show later that the evidence does in fact point to the conception of a great overthrust.

The problem remained as Middlemiss left it for exactly fifty years. His map has been reproduced in both editions of 'A Sketch of the Geography and Geology of the Himalaya Mountains and Tibet' and in Wadia's 'Geology of India', but no attempt has been made in these publications to discuss the difficulties of structure implied by accepting the interpretation which Middlemiss adopted. His account was, however, read independently by Mr. West and myself, both of us feeling the excitement of the possibility of nappe structures latent in it.

III.—RECENT SURVEY, 1935-36.

During the last three seasons I have mapped east of Longitude 78°E. and have joined up the succession which I had established around Solon (described in 1934) with that of Middlemiss. Before reaching the Ganges river, I found both in 1935 and in 1936 structures in Tehri Garhwal which seemed to me to settle the validity of Middlemiss' condemned impression. Now, having examined part of the Garhwal area, some of it in detail, I am convinced of the existence of great overthrusts. There are, it is true, many difficulties involved in a region almost devoid of fossiliferous rocks, except the Tal limestone, (the fossils in which are so broken that no certain age has been assigned to them) and the Nummulitics, and in which there appear to be recurrences of rock types throughout the assumed stratigraphical succession. Yet some of the features seem clear and worth recording apart from those that are less explicable.

The following tables give the stratigraphical and tectonic successions which I have determined east of Longitude 78°. To the second table has been added the succession found by Middlemiss in Garhwal in 1887 :—

Succession east of Longitude 78°E.

Formations.	Unconformities.	Approximate Maximum Thickness.	Probable age.
Siwalik	..	16,000	Upper Miocene to Pleistocene.
	?		
Murree (almost absent east of Long. 78°)	..	?	Lower Miocene.
	?		
Nummulitic	..	?	Eocene.
	unconformity		
Tallimestone and Calc grit	..	200	Upper Cretaceous ?
	unconformity		
Tal { Upper Tal quartzites	..	4,500	Cretaceous } ?
Tal { Lower Tal shales	..	2,000	Jurassic } ?
	unconformity		
Krol { Upper Krol dolomites, limestones and shales.	..	3,000	Trias } ?
Krol { Krol red shales	..	} 1,000	Permian } ?
Krol { Lower Krol limestones and shales	..	} 1,000	Permian } ?
Blaini { Infra Krol slates	..	} 2,000	? Talchir (Uralian).
Blaini { Upper Blaini boulder bed and dolomite.	..	} 2,000	? Talchir (Uralian).
	unconformity		
Blaini { Blaini slates	..	} 2,000	? Talchir (Uralian).
Blaini { Lower Blaini boulder bed	..	} 2,000	? Talchir (Uralian).
	unconformity		
Nagthat	..	3,000	Devonian ?
	unconformity		
Chandpur	..	4,000?	Lower Palæozoic and pre-Cambrian?
Simla slates, possibly equivalent to the Chandpur series, although different in lithology.	..	..	
Dolerites	..	..	Late Tertiary.

Note.
——— = Conformity.
—~~~— = Unconformity.

Tectonic Succession in Tehri Garhwal and British Garhwal.

——	Tehri Garhwal and British Garhwal.	British Garhwal, Middlemiss, 1887.
Garhwal Nappes .	Chandpur (metamorphosed). ——— *thrust* ——— Nagthat, Chandpur (little metamorphosed). Boulder beds, slates and limestones of uncertain stratigraphical horizon occur in one outlier below metamorphosed Chandpurs.	Inner Schistose series.
—— *Garhwal Thrust* ——		—— *reversed fault* ——
Krol Nappe . .	Nummulitic . . . . . Tal . . . . Krol. . . . . . . Blaini . . . . . . Nagthat, Chandpur (metamorphosed and unmetamorphosed).	Nummulitic. Tal. Massive Limestone. Volcanic Breccia in an undifferentiated group of Purple Slates
—— *Krol Thrust* ——		
Autochthonous . . .	Dagshai, Nummulitic Siwalik Simla slates.	

1. Autochthonous.

1. SIWALIKS.

The structure of the Siwaliks east of the Ganges has already been described by Middlemiss, whose illustrative sections are classics in Indian geological literature. Between the Jumna and Ganges rivers the main structure is an anticline in the Siwalik Range (the axis of which is slightly oblique to the topographical alignment of the range), a syncline forming the Dun valley, and to the north-east an overturned anticline which is truncated on the north side by the Main Boundary Fault and the Krol Thrust. The base of the Siwaliks is nowhere seen, but it is presumed that it consists of Nummulitics with attenuated Dagshai rocks resting on Simla slates; Section 1, Plate 37.

2. DAGSHAI AND NUMMULITICS.

The Main Boundary Fault, in the sense originally used by Medlicott, separates the Siwaliks from the older Tertiaries which have been thrust upon them. East of Long. 78° the Dagshai rocks (Murrees) are very seldom seen, and the chief fault is the Krol thrust which has brought pre-Tertiaries forward so as to rest directly on Siwaliks. This Krol Thrust has been called the Main Boundary Fault both by Middlemiss and myself, but, although it does in fact form the northern boundary of the Siwaliks over some of the area between Dehra and Naini Tal, it is not the same fault as that to which Medlicott originally assigned the term[1].

In the neighbourhood of Solon and Subathu, Dagshai and Subathu rocks (Murree and Nummulitic) rest upon Simla slates and have been overthrust by the rocks of the Krol Nappe. This is well seen around the north-west end of Pachmunda Hill and along the Blaini river[2].

Dagshai rocks are seen along the Tons river by Kalawar (30° 32′ : 77° 49′), on the left bank of the Amlawa river at Kalsi, and as a very narrow outcrop running in a south-east direction to about Long. 78° 02½′. They are thrust by a steep reversed fault (Main Boundary) upon Nahan rocks and are themselves overthrust at a gentler angle by pre-Tertiaries (Krol Thrust). Lenticles of fossiliferous limestone in the Dagshai rocks of the Tons river suggest that Nummulitics may be present there as well.

Between Dehra and Rikhikesh, Nummulitics together with cindery nodular sandstones, which are probably Dagshai, rest upon Simla slates and have been overthrust by the rocks of the Krol Nappe. They occur in two windows which will be described in greater detail in the next section. Probable Tal rocks occur, though poorly exposed, in the Chandna Rao at 30° 10′ : 78° 15′ evidently to the south-west of the Krol Thrust and belonging to the same tectonic horizon as the complex Nummulitic and Tal association of Banas Talla and Banas Malla (29° 57′ : 78° 21′).

[1] Middlemiss, C. S., *Mem. Geol. Surv. Ind.*, XXIV, pp. 19, 31, (1890); *Mem. Geol. Surv. Ind.*, XXXVIII, p. 337, (1908).
Auden, J. B., *Rec. Geol. Surv. Ind.*, LXVII, p. 431, (1934).
[2] *Rec. Geol. Surv. Ind.*, LXVII, p. 436, (1934).

Within the Himalaya, Nummulitics are seen resting upon Simla slates at Sayasu (30° 42′ : 77° 44′), and from just north of Dabra (30° 40′ : 77° 49′) down to the Tons river. In the Tons river Dagshai rocks are almost certainly present in addition to the Nummulitics.

Numerous faults and thrusts occur in the rocks of this zone. It is possible also that the Tertiaries may have been pushed bodily over the Simla slate foundation, with the Nummulitics acting as a lubricating horizon, in a manner comparable to the anhydrite horizon at the base of the Mesozoic succession of the Jura Mountains. These movements are probably, however, of less magnitude than those involved in the Krol and Garhwal Nappes, and the term 'autochthonous' seems to be justified.

2. Krol Nappe.

The maximum thickness of the succession in the Krol Nappe is of the order of 20,000 feet (6,100 meters). This succession is a normal one, for the disposition of numerous exposures of current bedding in the calc grit of the Tal limestone, and in the Tal and Nagthat quartzites, shows that these particular stages are not inverted, and therefore that the whole succession is in the correct order. This is important because it eliminates the possibility of repetition of certain facies by recumbent folding. Thus, the Tal and Nagthat quartzites cannot be regarded as belonging to a single horizon which has been duplicated by recumbent folding around a core of Upper Krol limestone. This conclusion is also supported by the fact that the sequence of stages above the Upper Krol limestone, on the assumption that this is the core of a recumbent fold, is not the mirror-image reverse of that below the limestone. In particular, there is no equivalent of the Blaini boulder beds in a position between the Lower Tal shales and the Upper Tal quartzites, which would be expected if the Tal and Nagthat quartzites were the same horizon duplicated in a flat overfold. Moreover, there are lithological differences between the Tal and Nagthat quartzites which, though not absolute when regarded singly, are collectively valid enough to differentiate these two stages. This point has been stressed because Middlemiss evidently confused these two quartzites. At the beginning of his survey he considered the Tals to underlie the Massive (Krol)

Lack of inversion.

limestone, but he was later compelled to reverse their position and to place them above the limestone. He appears also in places to have mapped the true Tal quartzites and the Nagthat quartzites that have been overthrust upon the Tals, both as Tal.

It may be accepted therefore that the sequence given for the Krol Nappe is uninverted and has not been duplicated by recumbent folding. Nor do I think it possible to assume the duplication by thrusting of uninverted stages one upon another.

The evidence for the existence of this nappe is based upon the following considerations :—

(1) The most convincing evidence is the occurrence of two windows disclosing Nummulitics and Simla slates between Dehra and Rikhikesh. One of these windows occurs on both sides of the Bidhalna Rao (30° 16′ : 78° 14′) and is about six square miles in area. The other window is well seen between Pharat (30° 13′ : 78° 18′) and Banali (30° 11′ : 78° 20′) and covers about seven square miles[1]. They occur along the anticlinal axis which separates the Mussoorie syncline of Nagthat-Blaini-Krol-Tal rocks from the Garhwal syncline lying to the south of and *en echelon* with it. In the centres of the windows occur Simla slates, generally with steep dips. Above the Simla slates, sometimes as isolated cappings, more typically as a border to the windows, are found Nummulitic shales and limestones together with blocks of highly shattered quartzites, the surfaces of which are glazed by friction. Finally, above the Nummulitic and associated rocks occurs the unmetamorphosed facies of the Chandpur beds, belonging to the Krol Nappe. There can be little question here of the Nummulitics occurring as outliers in pockets of a late Cretaceous erosion topography. Such a manner of occurrence would not account for the difference in type of the slates found above and below the Nummulitics. While it is admittedly difficult in some places to distinguish the Simla slates from the Chandpur series (which are possibly of the same age but deposited in two distinct areas), the difference between these two series is on the whole marked enough in this particular region, so that the occurrence of the Nummulitics between the Simla slates and the Chandpurs is significant. The upward succession in these windows, Simla slates—Nummulitics—Chandpurs, is the characteristic

[1] This Banali should not be confused with another village of the same name situated at 30° 18′: 78° 17′30″. The latter village is located on an outlier of the Garhwal Nappes (page 422).

feature, the disposition of the Nummulitics being such as to suggest that they are part of a continuous sequence, a sequence which I conclude to be tectonic. The strong shattering of the quartzites associated with the Nummulitics, their slip-polished surfaces, and their haphazard tectonic isolation as blocks in the shales, with no signs of orderly sedimentation, suggest that these rocks have been subjected to violent stresses. Indeed, below Banali the Nummulitic shales are converted into a 'pseudo-schist', resembling biotite-schist, but in reality a highly sheared shale endowed with abundant reflecting slip surfaces. These effects must have arisen during the Miocene movements, which are known to have been a characteristic feature of Himalayan tectonics, and are indicative of shearing stress rather than simple hydrostatic pressure. On the hypothesis that the Nummulitics rest upon a pre-Tertiary erosion topography, it would, however, be necessary to assume that this topography had undergone little change throughout the Tertiary and Quarternary eras. This would hardly be expected in view both of the extent of the Miocene movements, and of the great erosion which has taken place since then. If Miocene compression had shortened the width of the postulated valleys in which the Nummulitics had been deposited, so as to cause the infolding of the Nummulitics within the Chandpur and Simla slate series, it should have had a devastating effect on the pre-Tertiary north-south ridge separating these valleys. Yet the Chandpur beds of the narrow Diuli (30° 13′ : 78° 17′) ridge are neither shattered nor highly folded. The shattering occurs in the Nummulitic rocks which dip under the Chandpurs on either side of the ridge. In the view here adopted, the Nummulitics were deposited upon a more or less peneplaned surface of Simla slates, and were later overthrust by the Chandpur series of the Krol Nappe. The valleys in which the inferred windows are now exposed are regarded as the result of recent river erosion. Young river-gravels occur 800 feet above the level of these modern valleys.

(2) Between Solon and Subathu there is a similar disposition to that just described, except that the Chandpur and Nagthat beds of the Krol Nappe are missing. Here the sequence working upwards is :—Simla slates—Subathu (Nummulitic)—Blaini. This area has already been described, being figured on page 436, and discussed on pages 434-437 of *Records, Geological Survey of India*, 67, (1934). Near Solon there are two outcrops of Nummulitics, surrounded by Infra-Krol (Blaini *sensu lato*) slates, which I regard

as windows. The contacts between the Nummulitics and adjacent Blaini rocks are poorly exposed, and it might be maintained that the Nummulitics of these outcrops occur as eroded outliers upon Blaini. Nummulitics are known to lie infolded within Krol limestones at Bagar (30° 45′ : 77° 17′) evidently having overlapped the Tal rocks towards the north-west so as to rest directly upon the Krols, and it might be argued that this overlap continues in the direction of Solon across the Krol limestones on to the Infra-Krol (Blaini). The Krol limestones are, however, very well exposed near Solon, the type locality, so that this overlap could only be very local. Moreover, the same arguments apply to the Solon area as have just been given for the windows south-east of Dehra. Whatever doubts may be raised about these inferred windows, it is difficult, however, to escape the conclusion that the zig-zag disposition of the Simla slates—Nummulitic—Blaini-Krol rocks between Solon and Subathu represents the result of erosion of two tectonic units that had been brought together by thrust movements and were later folded. Here again, in a manner comparable to the windows already described south-east of Dehra, the contrasts between the Simla slates at the base of the Tertiaries and the Blaini slates above them is striking, precluding any explanation by simple infolding of Nummulitics within a single slate series.

(3) On the north-east side of the Krol syncline Nummulitics occur at Sayasu and Dabra, as has been already mentioned (page 417). They overlie Simla slates and appear to underlie the complex group of Chandpurs and Mandhalis. By Koruwa (30° 40′ : 77° 51′), and on the col south-east of Kailana, are found shattered and glazed quartzites exactly similar to those associated with the Nummulitics of the windows between Dehra and Rikhikesh, and around Banas Malla (29° 57′ : 78° 21′), again overlying Simla slates and underlying Mandhali limestones. The thrust which separates the Chandpur-Mandhali rocks from the Simla slates dips southwards, below the Krol syncline. It has been called the Tons thrust and I consider it almost certain that this thrust joins up below the Krol syncline with the north-dipping Krol Thrust on the south side. There is evidence for this supposition along the Huinl river in Tehri Garhwal.

Considering only the first two areas, the minimum displacement of the Krol Thrust and Nappe would be about five miles. Taking into consideration the region on the north side of the Krol syncline near Kailana, the minimum displacement is likely to be 20· miles (32 km.).

A point which should be emphasised in connection with the Chandpur and Nagthat series of the Krol Nappe is the increase in metamorphism which is observable from the south-west towards the north-east. Along the south-west side of the Mussoorie syncline, for example near Paled (30° 17′ : 78° 11′), the Chandpur series is in the condition of banded green slates and ash beds, while the Nagthat series is made up of soft sandstones and quartzites with a secondary silica cement. Towards the north-east both these series develop schistosity. The Chandpur slates are changed to schistose chlorite-sericite-phyllites, as at Jugargaon (30° 23′ : 78° 24′), while the arenaceous beds of the Nagthat series become schistose chlorite-sericite-quartzites, such as are well seen in the neighbourhood of Kaudia (30° 25′ : 78° 22′). The distance separating these contrasted grades of metamorphism is about 10 miles.

Metamorphism.

3. Garhwal Nappes.

1. OUTLIERS IN TEHRI GARHWAL STATE.

Ever since I had read Middlemiss's paper on the Physical Geology of West British Garhwal, I had hoped to find a structure in the centres of synclines in Sirmur State and Tehri Garhwal comparable to the one he had described, for I was convinced that the Massive limestone and Tal beds of Middlemiss were equivalent to the Krol limestone and the presumed Tals in Sirmur State. In 1931 a sandy current-bedded limestone was found at the top of the Tal series along the Nigali Dhar of Sirmur State (30° 39′ : 77° 34′) but unfortunately this was the highest horizon exposed[1]. It was not until March 1935 that the expected structure was found at the top of the Tal succession of the Mussoorie syncline on hill 6533 (30° 22′ : 78° 12′). Between Tashla (30° 22′ : 78° 11′), Satengal (30° 21′ : 78° 13′) and Hatwalgaon (30° 20′ : 78° 16′), there was found an outlier of schistose phyllites and subordinate white quartzites overlying a group of limestones, slates and boulder beds, both of which units rest upon and are surrounded by the Tal series. The

[1] *Rec. Geol. Sur. Ind.*, LXVII, Pl. 23, (1934).

area covered by this outlier is about 7 square miles. Equally convincing is another outlier of schistose phyllites lying upon the Tal series around Banali (30° 18′ : 78° 17′ 30″). This outlier is two square miles in area. Both outliers indisputably rest upon Tal beds with centripetal dips varying from 20° to 45°. Adjacent to the Banali outlier is a still smaller outlier, about 200,000 square yards in area, lying as a thin coating upon the Tal quartzites.

It is quite impossible to explain the position of the schistose phyllites upon the Tal series by ring-shaped reversed faults descending through the whole of the 17,000 feet of rocks of the Krol Nappe here present to its basement.

The Satengal outlier is complicated by the presence in its western part of slates, boulder beds, and a limestone identical to the Bansa limestone, which occur between the schistose phyllites and the underlying Tals. Nevertheless, whatever the stratigraphical position of these intervening beds may be, the fact of an overthrust of schistose phyllites upon the Tals is clear and beyond dispute. There is no such complication in the eastern part of the Satengal outlier or at Banali, where the schistose rocks lie directly upon the Tal series, locally with an angular discordance. I showed the Banali outlier to Professor Arnold Heim and Doctor Gansser, both of whom agreed that no doubt could be raised as to its overthrust nature.

The characteristic rock of these outliers is a green schistose chlorite-sericite-phyllite, with segregations of secondary chlorite in streaks. This type can be exactly matched with the rocks at the base of the Krol Nappe around Jugargaon (page 421). The fact that the underlying Tal and Nagthat quartzites are not inverted proves that the schistose phyllites of the outliers above them do not rest in that position as a result of duplication of the Chandpurs which occur at the base of the Krol Nappe by recumbent folding. If recumbent folding were present, either the Tal quartzites or the Nagthat quartzites should be inverted. Further indication of the lack of inversion is suggested by the presence of the limestone, mentioned above, which is similar to the Bansa limestone, and of boulder beds below the schistose phyllites of the Satengal outlier. This relationship is the same as that obtaining in the rocks at the base of the Krol Nappe between Kalsi and Chakrata, where the Bansa limestone and Mandhalis appear to underlie the Chandpur series. That is to say, both in the Krol Nappe and in the Garhwal

Nappe, there is the same succession upwards of these beds. The relationship is, it may be accepted, one of a thrust contact of the metamorphosed type of Chandpurs upon normally lying Tal beds.

In these two outliers of Tehri Garhwal there are two desirable features for demonstrating the complete overthrust of the schistose phyllites upon the Tal series :—

(1) Dips are everywhere centripetally inclined, but are not steep enough to bring the base of the schistose phyllites below the level of river erosion ;

(2) the two areas are of a size small enough to be seen almost as a whole by the eye from neighbouring peaks, so that the results of detailed mapping of the thrust boundary may be confirmed and integrated at a single glance.

2. OUTLIERS IN BRITISH GARHWAL.

In coming to the area mapped by Middlemiss in British Garhwal, these two features are absent. Dips are on the whole steeper, and the area is so large that it cannot be taken in by inspection from any one vantage point. I have re-mapped that part of Middlemiss's area which lies in sheet 53 J/S.W., and have traversed along the Nayar river from Byansghat to Bhanghat, Dwarikhal, Lansdowne (29° 51′ : 78° 41′) and Dogadda. The correlations given in table 2 are definitely proved by the results of detailed mapping. The only difference between the Garhwal area and that of Tehri Garhwal is that Nummulitics are present above the Tal series in Garhwal, while they are almost absent from Tehri Garhwal except for very narrow outcrops along the Ganges river. The outcrop of Nummulitics in Garhwal is discontinuous, but is slightly more extensive than shown by Middlemiss.

Overlying the Nummulitics in sheet 53 J/S.W. occur two separate nappes which are disposed in synclines that are separated for some distance by the anticlinal axis running from just east of Lachmanjhula in a south-east direction past Jogyana along the Huill river; Section 2. In the western, Amri, syncline (Amri: 30° 04′ : 78° 22′) the rocks are characteristically green schistose phyllites with subordinate white schistose quartzites, the assemblage recalling at once that of the Satengal and Banali outliers. In the eastern, Bijni, syncline (Bijni: 30° 04′ : 78° 25′) the dominant rocks are purple, green, and white quartzites exactly resembling the Nagthat series, with underlying and subordinate banded green slates similar to those of the less metamorphosed type of Chandpurs on the south-west side of the Krol Nappe. In the anticline separating these two nappes there crops out a complicated assemblage of Tal and Nummulitic rocks, obviously highly disturbed and interfolded, as may be well seen at Bagurgaon (29° 58′ : 78° 29′).

Between Kothar (29° 58′ : 78° 34′) and Lansdowne there is another and larger syncline of schistose phyllites and white schistose quartzites, similar to those of the Amri, Banali and Satengal synclinal outliers. Intruded into these rocks occurs the gneissic granite of Lansdowne.

It must be admitted at once that there are many difficulties in understanding the Garhwal area. Firstly, I have been able to come to no satisfactory conclusion about the true position of the boulder slate (volcanic breccia of Middlemiss). In the north end of the Garhwal syncline this boulder slate unquestionably joins up with the Blaini, but I am uncertain if the boulder slate so often found lying above the Tal beds of Garhwal is the same as the Blaini, thrust upon the Tals, or if it is an altogether different horizon. Secondly, as seen above, the outcrop of Middlemiss's Inner Schistose series is not made up of a single tectonic unit. These difficulties can only be cleared up by detailed mapping, but, in spite of them, I am confident that the Inner Schistose series of Middlemiss does truly overlie the Nummulitic, Tal and Krol rocks as a thrust outlier. In no other way is it possible to explain the ring-shaped boundary between the older rocks and the Nummulitics around Amri and Palyalgaon (30° 06′ : 78° 24′). Just north of Amri, Middlemiss mapped two faults separating the older rocks from the Nummulitics. The N.W.-S.E. fault is shown as terminating westwards against the N.-S. fault, which is made to pass northwards towards Patna, *without displacing the Nummulitic—Tal boundary*. On the postulate of Middlemiss, this fault should have caused the Outer Formations to be thrown down below their own basement. Its throw would be enormous, and yet it fails to displace the Nummulitic—Tal boundary at all. A re-examination of this area has shown that the schistose phyllites overlie the Nummulitics round an arc of 180° and that the boundary between them is continuous and not made up of the intersection of two or more faults. The reason is clear. The faulted junction between the schistose phyllites of Amri and the Nummulitics does not cut through the Nummulitics and underlying formations, because it is a thrust plane which lies at an horizon altogether above them ; Plate 35 and Plate 37, fig. 2.

Moreover, in the Garhwal area the rock types of the Inner Schistose series are dissimilar to those underlying the Krol series along the Nayar river, both in lithology and in strike. Underlying the Krols from Byansghat to Banghat (29° 57′ : 78° 42′) occur Simla slates with strikes varying from E.-W. to N.N.E.-S.S.W. The Krol—Tal rocks, and the overlying schistose rocks from Dwarikhal to Lansdowne, have a uniform N.W.-S.E. strike. The Simla slates also differ in lithology and degree of metamorphism from the rocks of the schistose series overlying the Krol and Tal series. On the interpretation of Middlemiss, the Simla slates and the Inner Schistose series should be the same, since the reverse faulting which he postulated would have brought up the same foundation rocks upon the Tals as underlie the Tal and Krol series.

It is difficult to picture the mechanics of the reversed faulting suggested by Middlemiss, since it is necessary to assume either that his Outer series have been thrust inwards and downwards towards a centre or that his Inner series has expanded outwards on all sides from a centre over the Outer series. Cone fractures are common features in certain volcanic areas such as the western islands of Scotland, but so far as I know the displacement along these fractures is inconsiderable and is largely a consequence of infilling with magma. The whole difficulty is removed if we accept that the present basin-like disposition is a secondary feature subsequently impressed upon an extensive thrust of the Garhwal units over the Krol unit.

In connection with the question of reversed faulting, I think that Mallet had a truer grasp of the solid geometry required by geological relationships similar to those of Garhwal. When mapping north Bengal and southern Sikkim he realised that the position of the Darjeeling gneiss above the Daling series could not be explained by 'mere local inversion along the lines of contact'[1]. So for as I have seen these rocks in eastern Nepal and Sikkim, the Darjeeling gneiss, though truly above the Daling series, does not appear to be separated from it by a thrust plane[2]. The point it is wished to emphasise here is that both in Garhwal and in eastern Nepal and Sikkim the observed relationship is one involving

[1] Mallet, F. R., *Mem. Geol. Surv. Ind.*, XI, p. 42, (1874).
[2] Auden, J. B., *Rec. Geol. Surv. Ind.*, LXIX, p. 161, (1935).

complete superposition and not local reversed faulting, even though the explanation offered for the manner of this superposition is different in the two cases.

The argument for an extensive thrust plane over the Nummulitic, Tal and Krol rocks of Garhwal may now be summarised.

(1) The Nummulitic, Tal and Krol rocks of Garhwal completely surround the Inner Schistose series (as shown by Middlemiss) and dip below them centripetally. This is well seen around Amri and Palyalgaon in sheet 53 J/S. W.

(2) At Satengal and Banali in Tehri Garhwal State, schistose phyllites lie as indisputable thrust outliers upon the Tal series.

(3) At least two synclines occur within the Inner Schistose series of Garhwal (those of Amri and Lansdowne) in which the schistose rocks are identical in every respect to those found in the indisputable overthrust outliers of Satengal and Banali. In the Lansdowne outlier there is an additional element in the presence of the gneissic granite, which was intruded before the thrust movements had taken place.

(4) Middlemiss argued on the grounds of metamorphism that the schistose series are older than the Nummulitics upon which they lie. Apart from the question of metamorphism, there is no known post-Nummulitic sequence to correspond to the schistose series. From both points of view the schistose series must lie with an abnormal contact upon the Nummulitics and Tal series.

(5) The Inner Schistose series is composed of two main units :—

(*a*) schistose phyllites, slates, schistose quartzites and quartzites, resembling the more metamorphosed facies of the Chandpur series of the Krol Nappe :

(*b*) banded grey-green slates and mainly purple quartzites, resembling the less metamorphosed facies of the Chandpur and Nagthat series of the Krol Nappe.

Neither of these two units resembles, in strike or closely in lithology, the Simla slates which occur at the base of the Outer series along the Nayar river. The more schistose rocks of the Inner series also differ from the Simla slates in metamorphic grade. These facts appear to negative the explanation given by Middlemiss of reversed faulting having brought up the basement of the Outer Formations so as to lie upon them. If reversed faulting had taken place, the basement rocks (Simla slates along the Nayar river) and the Inner Schistose series should be identical. In the solution suggested in this paper it is believed that the facts are best explained by two thrusts: the Garhwal Thrusts introducing rocks similar to those which in parts of sheet 53 J/S.W. lie at the base of the Krol Nappe, so as to rest above the Krol Nappe; and the Krol Thrust dividing off the Krol Nappe from the Simla slate foundation. This thrust is believed to be transgressive, both towards the south-east in Garhwal, and towards the north-west in Sirmur and Baghat States, with the result that it cuts out successive members from the base of the Krol Nappe.

I would suggest that the arguments given above are sufficient to establish the existence of a great system of thrusts upon the Nagthat-Blaini-Krol-Tal-Nummulitic succession in Tehri Garhwal and British Garhwal. These thrust-nappes exist now as three outliers:—

(1) Satengal outlier, covering about 7 square miles;
(2) Banali outlier, covering 2 square miles;
(3) Garhwal outlier, covering approximately 240 square miles.

The Bijni Nappe is possibly relatively local in origin, but the main nappe of the Garhwal system, which includes the Satengal and Banali outliers, and the Amri and Lansdowne synclines in the Garhwal outlier, has certainly travelled a great distance.

3. FURTHER OUTLIERS OF THE GARHWAL NAPPES.

Besides working in the Lansdowne area of British Garhwal, Middlemiss also mapped a syncline of schists and quartzites intruded by gneissic granite at Dudatoli (30° 03′ : 79° 12′)[1]. He pointed out (page 40) the exact similarity between the gneissic granites of Dudatoli and Lansdowne, and also (page 136) the fact that the only synclines of importance along a line from the Plains to the Main Himalayan Range are connected with the gneissose and schistose series. I would go further in believing that the schistose rocks into which the Dudatoli granite is intruded are the same as those of Lansdowne, Amri, Banali and Satengal, which have already been described. Similarly, the gneissic granite of Ranikhet and Dwarahat is intruded into phyllites of the same type.

There is no evidence in the regions in which I have mapped or traversed for the equivalent of the Jutogh series of Simla described

[1] *Rec. Geol. Surv. Ind.*, XX, pp. 40, 136, (1887).

by Pilgrim and West. The granites of Lansdowne, Dudatoli, Dwarahat and Ranikhet appear in all cases to be intruded into phyllites of one type, corresponding to the more metamorphosed facies of the Chandpurs. These rocks may possibly be equivalent to the Chail series of West. The local increase in metamorphism to garnet-chlorite-phyllite, garnet-chlorite-schist, fine-grained biotite-schist, chiastolite schist, which is attributable to contact effects in proximity to the intruded granites, appears to take place in the Chandpur series of schistose phyllites and not in a higher and altogether distinct series such as the Jutoghs of Simla. This fact I can state with certainty to be true of the Lansdowne area where it is definite that there is no additional series above the Chandpurs of the Inner Schistose group. My briefer examination of the Dwarahat-Dudatoli area suggests the same conclusion, one which seems inevitable indeed from the observations of Middlemiss, mentioned in the passage which I have quoted in an earlier paper[2]. In this passage he points out the gradation in a single series from schist to ordinary slate. Mr. West, in a recent discussion of this problem, accepted that the Jutogh Thrust may not be of widespread significance towards the south-east[3].

In all these cases, the schistose rocks, with or without intruded granite, appear to overlie in synclinal form less metamorphosed limestones and quartzites. Consequently, besides the three outliers of the Garhwal Nappes which I have discussed in detail above, I would suggest that the Dudatoli-Dwarahat-Ranikhet-Almora region also represents a syncline or group of synclines which may be outliers of the Garhwal Nappes. In the map (Plate 36) only one generalised syncline has been shown, since no detailed mapping has been done in this area, except by Middlemiss around Dudatoli.

4. Age of the Krol and Garhwal Thrusts.

The maximum age of the Krol Thrust is established by the presence below it of Nummulitic and Dagshai rocks. This thrust cannot, therefore, be older than Burdigalian.

Below the Garhwal Thrusts occur Nummulitics and possible Dagshai rocks. These thrusts are therefore certainly younger than

[1] *Rec. Geol. Surv. Ind.*, XX, p. 137, (1887).
[2] *Op. cit.*, LXVII, p. 412, (1934).
[3] *Current Science*, 111, p. , (1935).

the Eocene, and are possibly, as in the case of the Krol Thrust, not older than Miocene in age. This is in agreement with the recent discovery of Nummulitic and Dagshai rocks by Mr. West in the Shali area, below the Chail Thrust[1].

Since no Siwalik rocks are found in the windows, or below the outliers, it might be assumed that the thrust movements took place after the Burdigalian but before the Siwaliks had time to be deposited there, an assumption which would make the movement about Helvetian in age. If, however, the Siwaliks never extended so far to the north-east, this argument fails, since it is possible to imagine the thrusting to have occurred a considerable time after the Nummulitics and Dagshais had been laid down and while the Siwaliks were being deposited elsewhere.

That some of the movement along the Krol Thrust is more recent than Helvetian is proved by the frequent juxtaposition of pre-Tertiaries upon the Nahans between the Jumna river and north Bengal. Further, in places even the Upper Siwalik conglomerates are involved in overthrust by the pre-Tertiaries. Ten miles north-west of Dehra the boulders of these conglomerates are so shattered that it is impossible to obtain a hand specimen of them. Similar overthrusting occurs at Bilaspur on the Sutlej river (31° 20′ : 76° 45′)[2]. These movements must be of Lower Pleistocene or even of later age. Yet it is difficult to believe that the major horizontal movements of the Krol and Garhwal Nappes over a distance of several miles took place as late as this. By Lower Pleistocene times, the rising Himalayan chain must have been dissected to such an extent into blocks by deeply eroding streams that the upper nappes had already been worn away into outliers. The formation of these upper nappes can only have taken place before erosion had proceeded to such an extent that the outcrops of the nappes along an alignment in the direction of movement had been divided off into separate outliers, unable to translate the stresses as a unit. Both the Krol and Garhwal Nappes have been strongly folded, possibly as a result of the resistance offered by the floor upon which the movement was effected. There has since been erosion of these thrusts with the resulting formation of the windows and zig-zag outcrops, and it may be accepted that the major part of the movement along these thrusts took place before river dissection had

[1] *Rec. Geol. Surv. Ind.*, LXXI, p. 72, (1937).
[2] *Op. cit.*, LXVII, p. 444, (1934).

reached its present pronounced stage. It may, therefore, be assumed that there has been more than one period of movement, the stronger movements perhaps during the Helvetian, and the later movements during the Siwalik and post-Siwalik.

IV. SNOWY RANGES.

I have visited the higher Himalaya of this region twice; in 1932, when a traverse was made up the Alaknanda valley to Badrinath, Mana and the Arwa valley; and in 1935, when the Bhagirathi valley was ascended up to some of its tributary valleys in the neighbourhood of Harsil, Gangotri and Gaumukh. A brief lithological description of the rocks encountered along the Alaknanda valley has already appeared[1]. It is intended here to mention only a few points concerned with the snowy ranges of the higher Himalaya.

Two main zones.

The snowy ranges between the Bhagirathi and Alaknanda valleys may be divided into two zones by a fairly well defined line. The southern zone, forming the Main Himalayan Range as seen from Landour and Lansdowne, consists predominantly of paragneisses and schists, dipping towards the north-east, and presenting a scarp face towards the Plains of India. The northern zone is of granite, out of which the peaks in the Gangotri and Arwa basins are carved. The boundary between these two zones is shown on the map (Plate 37). I disagree with the mapping of Griesbach, who has drawn in the neighbourhood of Harsil and Dharali what appears to me to be an artificial boundary between Haimanta slates and a combined group of granite and metamorphics[2].

Metamorphics of the Main Himalayan Range.

The rocks of the Main Himalayan Range consist of a varied assemblage of schistose phyllites, schists, and granulites intruded by gneissic granite and pegmatite. They rest upon little metamorphosed shales, phyllites, limestones and quartzites, from which they are separated by a thrust plane. This thrust is well seen at Sini (30° 46′ : 78° 36′) and occurs near mile 158 on the pilgrim track from Hardwar to Badrinath. The rocks immediately above the thrust

[1] *Rec. Geol. Surv. Ind.*, LXIX, p. 133, (1935).
[2] *Mem. Geol. Surv. Ind.*, XXIII, (1891).

appear similar to those of the metamorphosed Chandpur series found in some places at the base of the Krol Nappe and more generally in the main Garhwal Nappe.

The main suite of metamorphosed sediments must belong to a different unit. The rocks of this suite were originally shales, shaly sandstones, sandstones, calcareous shales and limestones. In their present metamorphic condition they form a series that is characteristically granulitic, consisting of quartz-biotite-granulites, often with garnet and felspars, quartzites, hornblende-granulites, diopside-calciphyres, marbles, biotite-garnet-schists and kyanite-schists. The calcareous rocks are best developed between Badrinath and Mana, but occur to some extent up the Rudagaira valley (30° 55′ : 78° 54′). It is possible that this suite is equivalent to the Jutogh series of Simla.

Granite zone.

The granites to the north of the Main Himalayan Range probably occur continuously from Dharali (31° 02′ : 78° 47′) eastwards to the Saraswati valley and Kamet peak. Several types of granite are present, including muscovite-tourmaline-granite, biotite-muscovite-granite and adamellite. Porphyritic types are common at Bhaironghati, Jangla and up the Nela (Lamkaga) valley.

Some of these granites are sheared and crushed. The presence of patches of granular blue quartz is suggestive of crushing, a fact which struck my colleague Dr. J. A. Dunn on being shown specimens. Shearing is well seen at a height of 10,300 feet up the Nela valley (about three miles from Harsil), where there is a contact between the granite and overlying metamorphics. The garnet of the metamorphics has broken down retrogressively to chlorite, while the granite has been sheared and mylonitised through a width of 150 feet at right angles to the plane of contact, with the development of marked schistosity and the destruction of the phenocrysts.

It would appear from these facts that some at least of these granites are not post-tectonic in the sense of the post-tectonic granites which cut across the *decken* in the Alps. These strained granites may have been intruded either during the major thrust movements, or at an altogether earlier period. It was considered above that the Lansdowne granite was intruded before the formation of the Garhwal Thrust and that it was pre-Miocene.

V. POSSIBLE NORTHWARD EXTENSION OF THE GARHWAL NAPPES.

It has been stated that the main Garhwal Nappe occurs as synclinal outliers resting upon less metamorphosed rocks. Reasons have been brought forward for regarding the schistose rocks and granite of Dudatoli as belonging to the same overthrust unit as those of the Satengal, Banali, Amri and Lansdowne outliers. The nearest schistose rocks to the north-east from Dudatoli occur at the base of the Main Himalayan Range, where they too appear to lie with a thrust contact upon less altered limestones, quartzites and slates. It would seem possible, therefore, that the main Garhwal Nappe joins up with the rocks at the base of the Main Himalayan Range and that the minimum distance of translation of this tectonic unit may be about 50 miles (80 km.). It appears that the granites were intruded principally into the Garhwal and overlying units and were thrust with them for miles towards the south-west, over rocks which are free from granitic intrusions, but are in places considerably injected with basic magma.

Finally, comparison may be made with the eastern Himalaya. In eastern Nepal and north Bengal there are two main dislocations :—

(1) the thrust causing the Gondwana rocks to lie upon the Siwaliks :

(2) the thrust separating the Daling series from the underlying Gondwanas.

These two thrusts may be analogous respectively to the Krol Thrust and one of the Garhwal Thrusts. Near Udaipur Garhi (26° 57′ : 86° 32′) there are bleaching carbonaceous slates and a dark crystalline limestone which resemble the Blaini and Krol series of the western Himalaya, and which, like them, rest upon Siwalik rocks.[1] Further, it may be remarked that the schistose phyllites of the main Garhwal Nappe appear to be identical to the Daling series of Nepal and Sikkim. In both areas, these schistose rocks are thrust upon Gondwanas or the equivalent of Gondwanas.

VI. EXPLANATION OF PLATES.

PLATE 35.—Map No. 53 J/S. W., reduced to the scale of 1 inch =4 miles, showing the disposition of the main tectonic units in the neighbourhood of Dehra and Rikhikesh.

[1] *Rec. Geol. Surv. Ind.*, LXIX, p. 143, (1935).

PLATE 36.—Tectonic Sketch Map of the Garhwal Himalaya, including a portion of 1 : million map No. 53. This map is based on the surveys and traverses of C. S. Middlemiss, C. L. Griesbach, and J. B. Auden. Auden alone is responsible for the tectonic interpretation of the geological results. The limits of the inferred Garhwal Nappe between Dudatoli and Ranikhet are conjectural.

PLATE 37, FIG. 1.—Section across Siwalik Range and Lower Himalaya in 1" 2 miles map No. 53 J/S.W.

FIG. 2.—Section across the composite Garhwal Syncline showing Amri and Bijni Nappes and the unconformity below the upper Tal Calc. grit. (Scale 1"=1 mile.)

FIG. 3.—Tectonic section across the Garhwal Himalaya. A preliminary attempt. (Scale 1"=8 miles.)

MISCELLANEOUS NOTES.

An inclusion of coaly shale in Deccan Trap at Indore, Central India.

Discovery of inclusion.

In July, 1934, the Director of the Institute of Plant Industry sent a sample of 'coal' discovered at a depth of 19 feet from the surface as an inclusion in 'black trap rock' at Indore (22° 43′ : 75° 51′), Central India, during blasting operations in the course of digging a well.

Analyses.

Dr. M. S. Krishnan, who was Curator of the Geological Museum at that time, reported the specimen as 'shaly coal, dull black in colour and showing fine bright streaks of material (presumably of the nature of vitrain)'. It was analysed in this laboratory with the following results, an analysis by Mr. Y. Wad, Chemist to the Institute of Plant Industry, being given for purposes of comparison :—

	Per cent.	Per cent.
Moisture	2·80	..
Volatile matter	20·23	16·595
Fixed carbon	18·92	..
Ash	58·05	58·03
	100·00	
Specific gravity	1·88	2·04
Caking properties	Does not cake	..
Colour of ash	Pink-buff	..
Analyst	Mahadeo Ram	Y. Wad.

The specimen is thus a coaly shale as it contains more than 50 per cent. ash.[1] The powdered mass is registered as N. 857 in the collections of this Department.

Further details of mode of occurrence.

Further correspondence elicited the information that the size of the coaly shale as found was approximately 12 inches × 15 inches × 9 inches. As the well in which the inclusion was found was full of water, it was not possible to send specimens of the rock in which it was embedded until March, 1935, when specimens of trap from above and below the coaly shale were received from Indore.

[1] Fermor, L. L., *Rec. Geol. Surv. Ind.*, LX, p. 345, (1928).

These were collected in the well at depths of 18 feet (47/867, 23888), 21 feet (47/868, 23889), and 23 feet (47/869, 23890) respectively, the first being above the site of the inclusion, and the two latter below it.

Examination of specimens and sections of trap.

The specimens and sections were examined by Sir Lewis Fermor who stated :—'The specimens of both the overlying trap are of porphyritic basalt containing not only abundant phenocrysts of plagioclase, but also altered phenocrysts of olivine, now completely altered to what is probably delessite, with iddingsite in one case. They might be parts of the same flow, the highest specimens showing vesicular tendencies.'

Additional sections of trap.

As a result of doubts as to the authenticity of the occurrence, advantage was taken of the visits of Mr. W. D. West to Indore in connection with the Indian Science Congress, and he was requested kindly to examine the well in question. Mr. West stated :—

'When I visited Indore in October, 1935, the water-level in the well was too high for me to see anything. In January, 1936, however, the water-level was about 25 feet below ground-level. Thanks to Mr. F. K. Jackson, in whose compound the well is, I was able to descend into the well by sitting on a *charpoy* which was let down with ropes. This gave me a good view of the sides of the well all round.

It is quite clear that there is now no trace of coaly shale anywhere in the sides of the well. The information at Indore suggested that the coaly shale was a large "lump" situated towards one side of the well, and not a seam. It occurred 19 feet down. My own observations showed that the sides of the well are entirely trap, and it is clear that the whole of the coaly shale must have been removed when the well was sunk.

Examination of the sides of the well suggested that there might have been a flow junction at 16½ feet down. At this level, there was rather a sharp line all round the well, below which the trap was very "platy" for six or eight inches, while above and below it was more massive. I could see no abundant vesicles near this point.

Cursory examination of the microscope slides (24496-24499) of the rock above and below the possible junction showed that there are slight differences in the rocks, but I did not have time before leaving for camp to examine the slides very thoroughly. There was nothing to suggest it was a dyke.

There is no doubt whatever regarding the authenticity of the discovery. Unfortunately there is no more of the rock left at Indore.'

Various theories have been put forward to explain this occurrence, but the one that seems to have most support is that the inclusion is part of an intertrappean shale caught up by a trap flow. Whatever the origin, the occurrence has great interest, and for this reason it is recorded herewith.

Possible origin.

A. L. COULSON.

Octahedral Pyrite Crystals from the Kohat District, North-West Frontier Province.

My colleague, Dr. J. A. Dunn, identified as pyrite certain small, slightly distorted, octahedral crystals which I had given me at Kark (formerly Kharak; 33° 7′ : 71° 5′ 30″) in the Kohat district, North-West Frontier Province, when I was inspecting the local oil-shale occurrences in January, 1936. The crystals are found commonly along the Tarkha Algad near Kark in a ?Laki gypseous series overlying the salt marl and are collected by the local small boys. The largest crystals have axes of 7-8 mm., but most crystals have axes of about 5-6 mm.

After the thin göthite covering had been removed by sandpaper from its faces, Mr. P. C. Roy kindly analysed one of the crystals of pyrite for me in the Laboratory of the Geological Survey of India with the following results:—

	Per cent.
Fe	47·09
S	52·40
	99·49

Dr. Dunn's polished section of a crystal showed no traces of magnetite but thin veins of göthite which were irregular in places and then followed cleavage planes. This göthite would account for the high percentage of iron, theoretical pyrite having 46·6 per cent. of iron and 53·4 per cent. of sulphur. A small amount of water must also be present.

Pyrite, of course, is a common mineral in the gypseous series referred to above, and its presence has been recorded often by Wynne and Pascoe amongst others. No reference seems to have been made, however, to crystal forms other than the cube and pyritohedron, though I have a recollection of reading of 'black diamonds', really pyrite crystals of octahedral shape, occurring in a series of age similar to the gypseous series at Kark.

Though Ford[1] says the octahedral form of pyrite is 'also common', almost perfect octahedra of that mineral are rare as there is usually a development of pyritohedral faces with the octahedral. Octahedra certainly occur in Pennsylvania,[2] accompanied by rarer forms with curved faces. Dr. Dunn has noted octahedral faces on pyrite crystals in Bawdwin ores from Burma and Mr. B. C. Gupta has shown me octahedal faces on pyrites in association with quartz and calcite from Kerakibari (25° 45′ : 74° 12′) in the Todgarh tahsil of Ajmer-Merwara.[3] However it would appear that the occurrence of these small octahedra of pyrite near Kark is worthy of record.

A. L. COULSON.

Quarterly Statistics of Production of Coal, Gold and Petroleum in India : July to September, 1936.

Coal.

——	July.	August.	September.	Quarterly total for each Province.
	Tons.	Tons.	Tons.	Tons.
Assam	18,218	17,783	15,994	51,995
Baluchistan	163	345	369	877
Bengal	465,455	524,006	602,413	1,591,874
Bihar	856,095	893,028	1,030,288	2,779,411
Orissa	3,003	1,692	2,475	7,170
Central Provinces	127,109	106,413	97,619	331,141
Punjab	4,306	4,418	10,615	19,339
TOTAL	1,474,349	1,547,685	1,759,773	4,781,807

[1] 'A Text-Book of Mineralogy', after Dana, p. 433, (1932).
[2] Penfield, *Amer. Journ. Sci.*, XXXVII, p. 209, (1889).
[3] *Mem. Geol. Surv. Ind.*, LXV, Pt. 2, p. 169, (1934).

Gold.

—	July.	August.	September.	Quarterly total for each Company.
	Ozs.	Ozs.	Ozs.	Ozs.
The Mysore Gold Mining Co., Ltd.	8,161	8,162	7,900	24,223
The Champion Reef Gold Mines of India, Ltd.	5,885	5,884	5,694	17,463
The Ooregam Gold Mining Company of India, Ltd.	4,349	4,338	4,379	13,066
The Nundydroog Mines, Ltd. .	9,635	9,637	9,619	28,891
TOTAL .	28,030	28,021	27,592	83,643

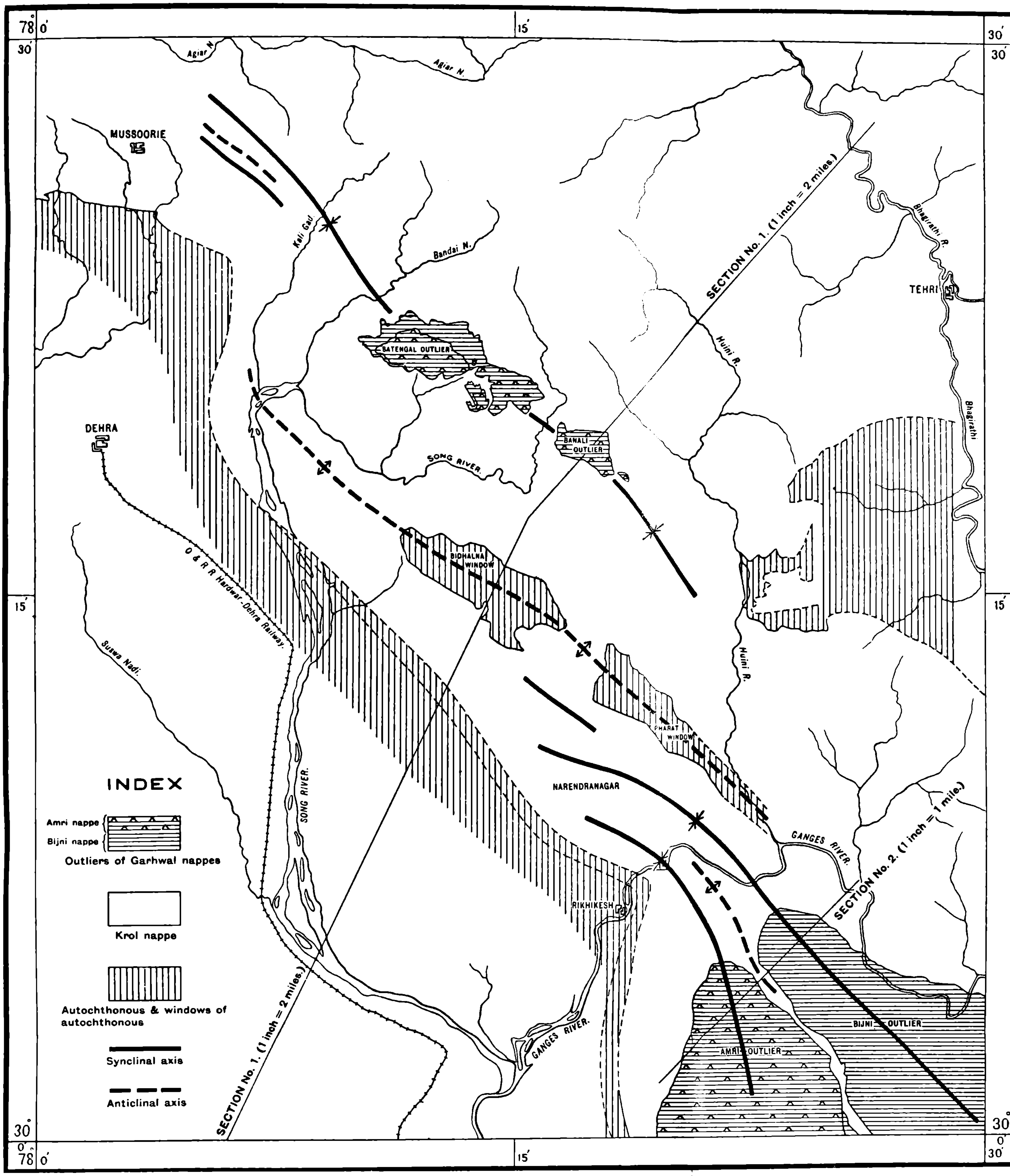
Petroleum.

—	Crude Petroleum.	Total gasolene from natural gas.*
	Gallons.	Gallons.
Assam	16,353,632	*Nil.*
Burma	67,489,517	2,222,493
Punjab	996,720	114,606
TOTAL .	84,839,869	2,337,099

* These figures represent the total amounts of gasolene derived from natural gas at the well-head. Of these amounts, a portion is sold locally as 'petrol' and the remainder is mixed with the crude petroleum and sent to the refineries. The figures given in the two columns, therefore, together represent the total 'raw products' obtained. These remarks apply to the similar totals quoted in previous *Records*.

A. M. HERON.

Records, Vol. 71, Pl. 35.



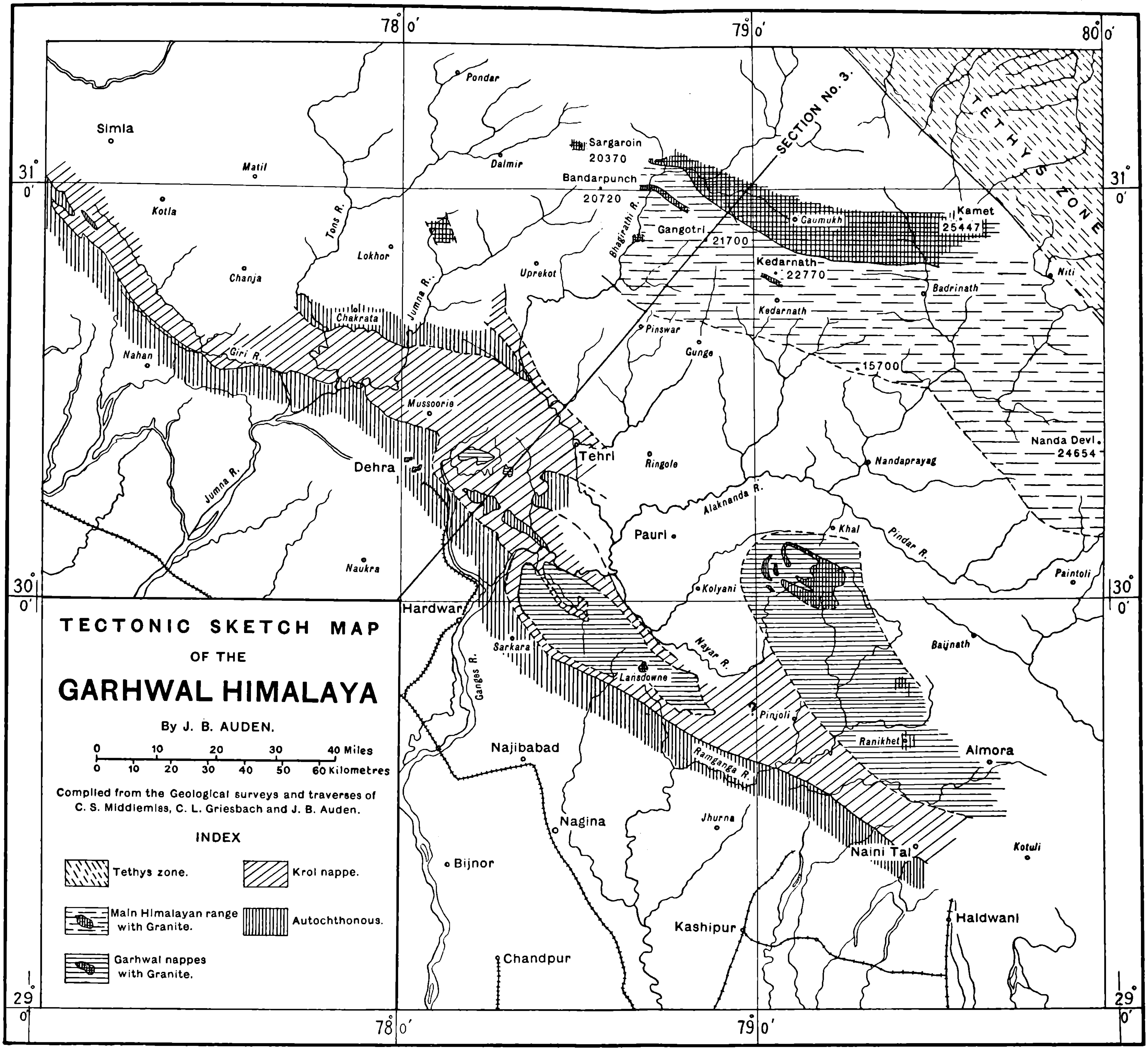
S. N. Guine, del.

G. S. I., Calcutta.

TRACING FROM SHEET 53 J/S.W.

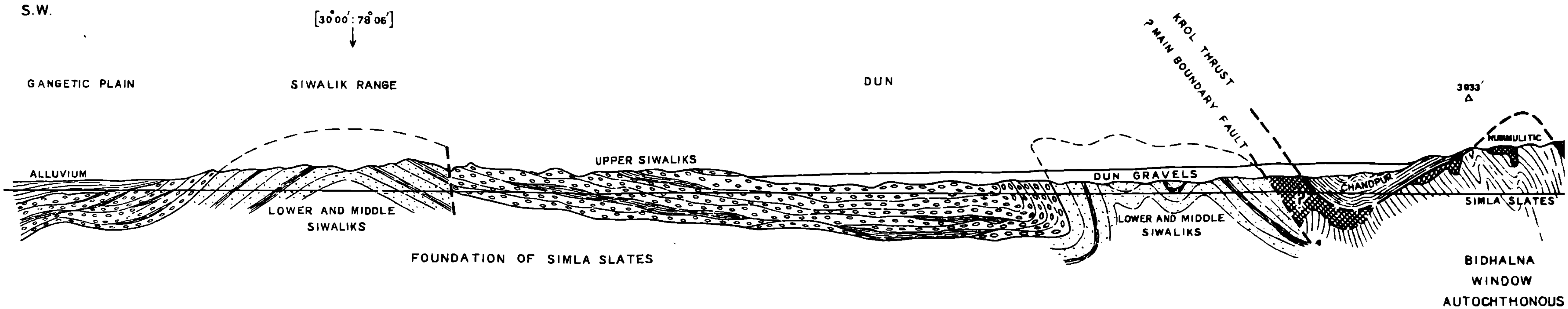
Showing distribution of tectonic units.

Scale, 1 inch = 4 miles.



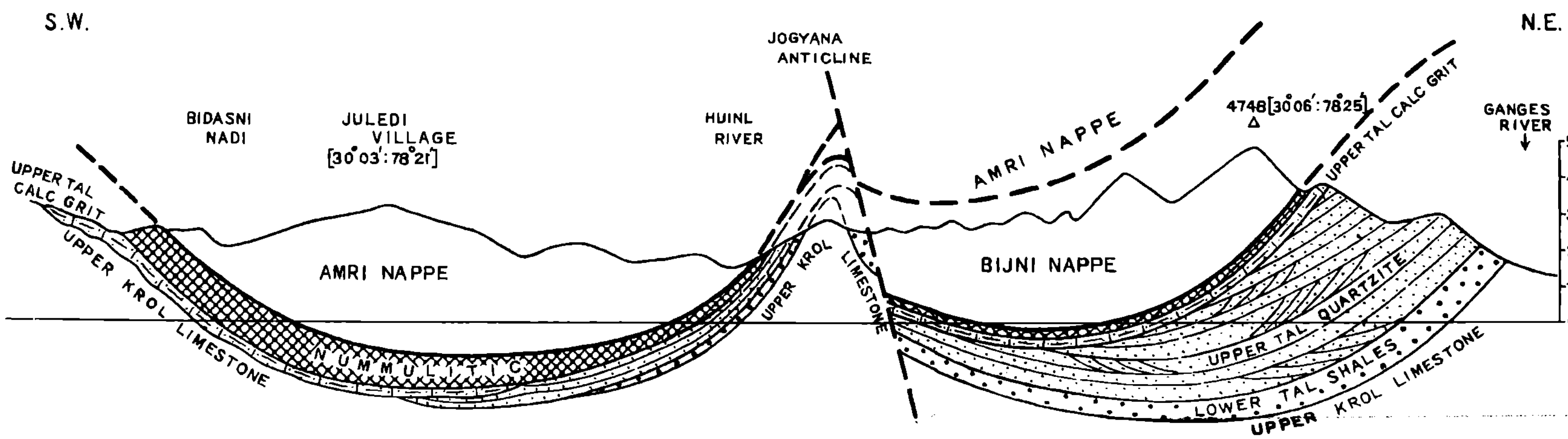
A. K. Ghosh, del.

G. S. I., Calcutta.

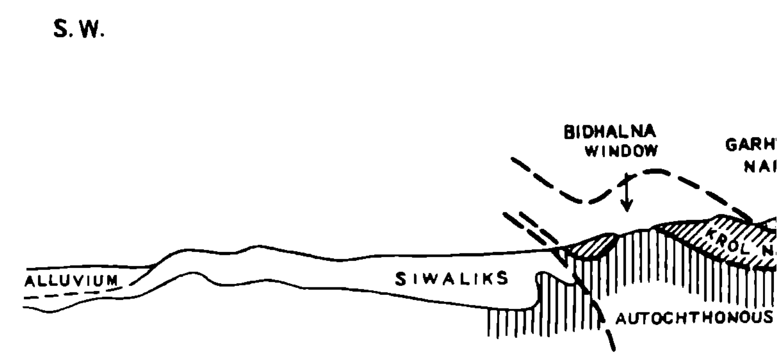


SECTION No. 1.—SECTION ACROSS SIWALIK RANGE AND LOWER HIMALAYA IN 1 II

Horizontal and Vertical Scale, 1 inch = 2 miles (1 : 126, 72(



SECTION No. 2.—SECTION ACROSS THE COMPOSITE GARHWAL SYNCLINE SHOWING AMRI AND BIJNI NAPPES AND THE UNCONFORMITY BELOW THE UPPER TAL CALC GRIT.



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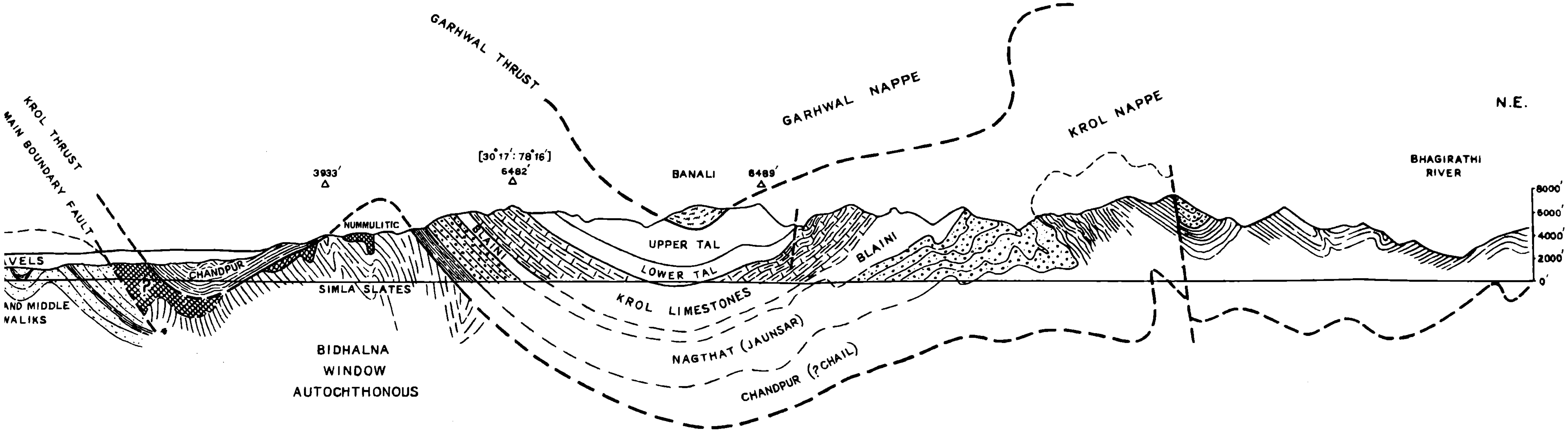
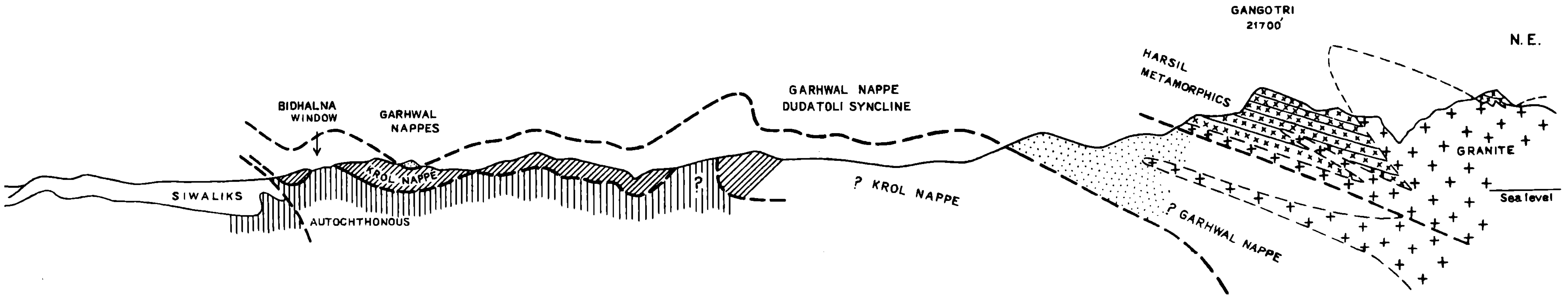
Records, Vol. 71, Pl. 37.



IWALIK RANGE AND LOWER HIMALAYA IN 1 INCH = 2 MILES MAP No. 53J/S.W.

zontal and Vertical Scale, 1 inch = 2 miles (1 : 126, 720).



SECTION No. 3.—TECTONIC SECTION ACROSS THE GARHWAL HIMALAYA.

A preliminary attempt.